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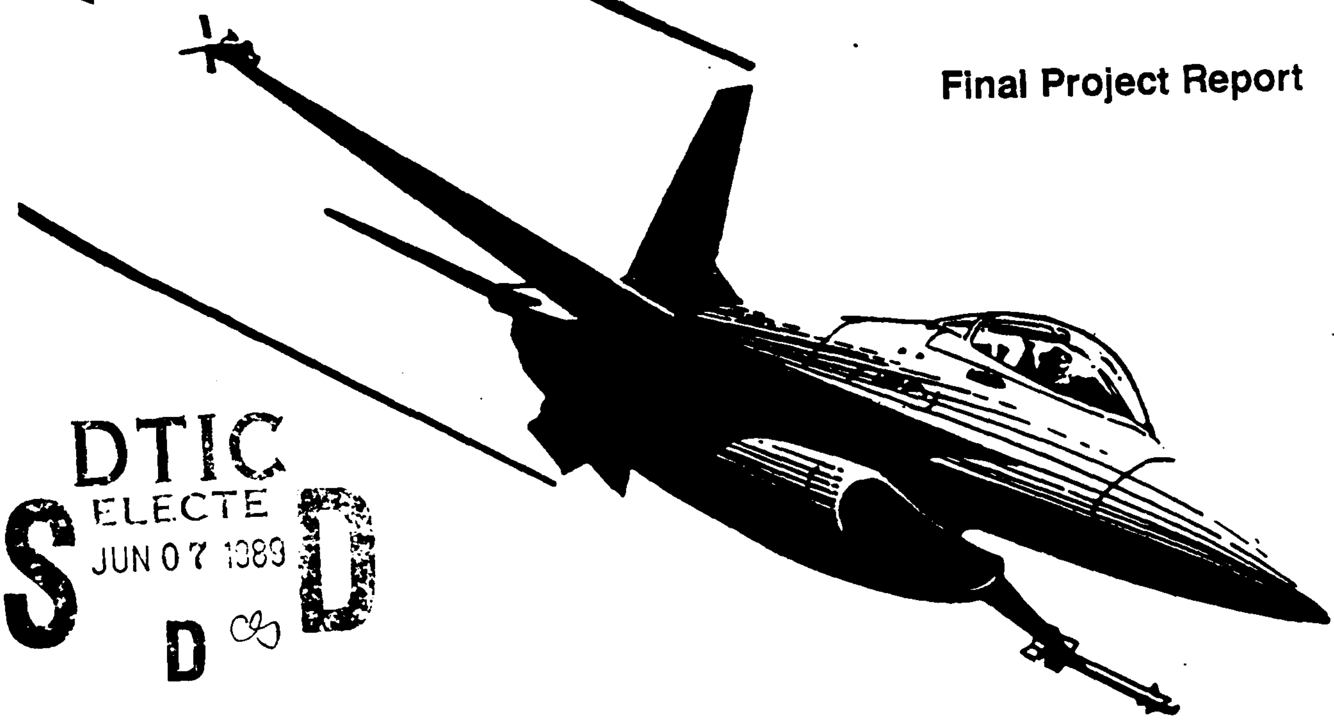
GENERAL DYNAMICS
FORT WORTH DIVISION

INDUSTRIAL TECHNOLOGY MODERNIZATION PROGRAM

Phase 2

Final Project Report



PROJECT 32

FACTORY VISION

Honeywell
Military Avionics Division

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This project deals with the evaluation, development and implementation of a system in the printed wiring assembly area that will provide for the electronic distribution of CAD/CAM product/process information to the shop floor through a network of graphics terminals. The system is expected to provide savings in increased labor productivity, reduction in group leader and setup labor, and reduced production engineering effort to create process information. In addition, the project should reduce the throughput time and human error problems by providing better graphic instructions in a more controlled real-time environment.

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GENERAL DYNAMICS
FORT WORTH DIVISION

INDUSTRIAL TECHNOLOGY MODERNIZATION PROGRAM

PROJECT 32

PHASE 2 FINAL PROJECT REPORT

FACTORY VISION

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PROJECT 32 -- FINAL REPORT

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PROJECT 32 -- FINAL PROJECT REPORT

FACTORY VISION

SECTION 1

INTRODUCTION

Project 32 addresses the Printed Wiring Assembly (PWA) facility at Honeywell's Flight System Operations, Military Avionics Division (MAvD) located in St. Louis Park, Minnesota, a suburb of Minneapolis. The PWA facility assembles, solders, in-circuit tests, and conformal coats printed wiring assemblies to various military specifications for a wide variety of "black boxes" used in a diversity of airframes. The approximate size of the PWB's being manufactured in this facility is 2" x 3" with the larger at 6" x 9" with the most common size at 6" x 6". The component population is from 2 to 300 components.

The PWA manufacturing facility consists of 80 operator workstations arranged along an automated material handling system that schedules work priorities.

The PWA Production Engineering Department is responsible for determining the processes by which the PWA's will be built. These responsibilities include generating the detailed process instructions for the PWA's, generating the numerical control (NC) program instructions for factory assembly equipment, controlling the process instructions and NC programs, and assuring that the process instructions and NC programs are distributed to the factory in a timely manner.

Project 32 deals with these functions as five cells which are identified as follows:

1. Create Process Cell
2. Storage and Control Cell
3. Electronic Distribution Cell
4. Set-up Optimization for Automatic Insertion Cell
5. Machine Interface Cell

In the "As-Is" condition, these five cells are, to a large degree, manually accomplished through a non-integrated paper based system.

In the "To-Be" condition the Project 32 objective was to integrate these five cells through existing computer technology. Some of the key features of this approach would be:

1. An interface with the division's Computer Aided Design (CAD) system as a source for deriving process information.

2. High-powered engineering workstations to enable the Production Engineers to create the PWA processes in an automated fashion.

3. Storage of the process information, i.e. text, graphics, and machine programs, on a factory computer.

4. Distribution of the process information to the factory operators through a network of shop floor graphics terminals.

5. Use of the factory computer to generate optimized family set-ups for the automatic insertion process.

6. Interface of the factory computer to the factory assembly machines to facilitate the distribution of NC machine programs.

The Project 32 Phase 2 Development and Factory Pilot efforts consisted of a thorough evaluation, both technically and financially, of a system which would perform functions required by the five cells.

As a result of the Phase 2 Development and Factory Pilot efforts it was determined that four of the five cells are technically feasible for Phase 3 implementation at this time. The "Create Process Cell", the "Storage and Control Cell", the "Set-up Optimization for Automatic Insertion Cell", and the "Machine Interface Cell" are the four cells recommended for Phase 3 implementation at this time.

The cell which provides the electronic distribution function is not technically achievable in a manner which will meet our requirements during the 1988 time frame. Additional effort will be required to develop the desired capability for this cell. "The Electronic Distribution Cell" will be discussed in detail under Section 17, Areas for Future Concerns/Development.

This Final Report justifies the expenditures for such a system based on savings in the areas of increased Production Engineering productivity in creating production process information, and reduced set-up time for assembly machines.

SECTION 2

PROJECT PURPOSE/OVERVIEW

The objective of this project is to provide a method of creating, controlling, storing, and distributing shop floor production process information electronically. The shop floor production process information, such as text, graphics, and machine programs, will be derived from the MAvD's Computer Aided Design (CAD) data base and/or created on high-powered production engineering workstations. This information will be stored in the computer and distributed to shop floor graphics terminals at each workstation along the PWA line, and also to factory equipment such as the universal automatic insertion machines and the CS-400B semi-automatic insertion machines. The system software will assure that the proper process data will be electronically distributed to the right workcenter at the right time. Factory machines presently operating on programs residing on Numerical Control (NC) tapes and floppy disks will be interfaced directly to the system.

The system will accomplish these objectives through:

- Interface to the MAvD's CAD system as a source for deriving production process information.
- Use of a Computervision CADDSERVER system by Production Engineering for creating the production process information.
- Use of Honeywell developed software which will be hosted on the CADDSERVER system and will automate the Production Engineer's job of creating the production process information.
- Use of Honeywell developed software which will be hosted on the CADDSERVER system and will optimize the machine set-up for automatic insertion.
- Storage of the production process information, i.e. text, graphics, and machine programs on the CADDSERVER system.
- Direct links from the CADDSERVER system to the Universal Axial and Dual In-line Package (DIP) insertion machines and the Contact Systems semi-automatic insertion machines.

The cell which provides the electronic distribution to shop floor terminals is not technically achievable in a manner which meets our requirements during the 1988 time frame. Additional effort will be required to develop the desired capability for this cell. The "Electronic Distribution Cell" will be discussed in detail under Section 17, Areas for Future Concerns/Development.

SECTION 3

TECHNICAL APPROACH

SCOPE

Project 32 Phase 2 effort involved the investigation of technologies, hardware, software, systems integrations, and human factors required to meet the objectives of this project.

Initial evaluation of our requirements, initial design for the project, and initial evaluation of vendor equipment and software resulted in the following approaches being taken in the five project cells. Details on each cell are discussed below.

1. Create Process Cell

BACKGROUND

MAvD has over 1600 Printed Wiring Assembly part numbers in the process system. On an annual basis there are over 60 new PWA designs generated and also more than 1200 engineering changes to PWA's made which result in change issues to production process information. Due to the large volume, initial CBA data revealed significant benefits in the concept of automating that portion of the Productions Engineers' job which deals with the creation and change of production process information.

The concept of automating the creation and changes of PWA production process information is feasible due to the fact that a high percentage of these PWA's have intelligent CAD data bases from which to derive the production process information. The data bases have been developed in the Computervision CADDS-3 and CADDS-4X environments over the last ten years.

APPROACH

The objective for the "Create Process Cell" is to utilize the CAD data bases to extract from and build upon for the creation of the production process information, and to create the production process information in an automated fashion. Central to this approach is the elimination of the need to re-transcribe and re-create both graphics and text information as presented in the "As-Is" condition.

During Phase 2, it was determined that there was not software available in the marketplace which would meet our requirements for automated process generation. The study also revealed that the Computervision CADDS-4X data base and software provided a very good environment for the creation and change fo the PWA Process detail and Computer Aided Manufacturing (CAM) information by Production Engineering.

Finally, it was determined that the best solution would be internally developed software designed to operate in the CADDS-4X environment. Honeywell proceeded to develop prototype software which provides the following automation aids for the Production Engineer:

1. The partitioning of the PWA into appropriate assembly operations. (Creation of route information).

2. The creation of Operation Detail graphical instructions for PWA assembly.

3. The creation of machine programs and set-up information for the Universal axial and DIP inserters and the Contact Systems semi-automatic insertion machine.

4. The task of incorporating a large volume of Engineering Change Orders (ECO's) which may necessitate changing any or all of the above created information.

2. Storage and Control Cell

BACKGROUND

The "Storage and Control Cell" in the "As-Is" environment is simply a paperwork filing system with all the inherent problems of storage and control that go along with such a system.

APPROACH

In the "To-Be" environment, the "Storage and Control Cell" functionality will be accomplished electronically. The functionality is an inherent part of the CADDSERVER environment.

Since the Computervision CADDSERVER/CADDSTATION hardware platforms and the CADDS-4X software environment were selected for the "Create Process Cell", no additional vendor studies were initiated for the "Storage and Control Cell".

The electronic storage functionality will be accommodated via four disk drives attached to each CADDSERVER. The four drives can store over 2 gigabytes of data. The production process detail information, both graphics and text, and the machine NC-program data which are generated on the CADDSTATIONS in the "Create Process Cell" will be stored on the CADDSERVER's disk drives.

The control functionality will be accommodated through access control and password capabilities of the UNIX operating system software and the CADDS-4X software on the CADDSERVER. Admittance to the system will be controlled by log-in authorizations under control of a system administrator. Each data file on the system will have "read/write" access restrictions which are defined by the creator of the particular file. In other words, the Production Engineer who creates a particular piece of process information can restrict that information so that others can view the information but not change it.

Old revisions of the process data will be archived to magnetic tape through procedures under control of the system administrator. Daily backup of the process data to magnetic tape will also be performed by the administrator so that no data will be lost.

3. Electronic Distribution Cell

BACKGROUND

Due to the large volume of production process information generated in the "Create Process Cell" and the inherent problems with storage, control, and distribution in a "paper-based system", Project 32 addressed the feasibility of an "Electronic Distribution Cell" for the production process information.

APPROACH

The marketplace was evaluated for commercially available systems which would meet the requirements for electronic distribution of process information in the PWA factory. Computervision's Factoryvision product was the only system available which appeared to have the capability to meet the requirements.

Honeywell negotiated with Computervision to provide Factoryvision hardware and software for evaluation. The system was first evaluated in an engineering environment, and then moved into a Factory Pilot environment.

As a result of the Factory Pilot, the system requirements for the "Electronic Distribution Cell" were re-evaluated and re-determined, especially in the areas of system response and performance, operator interface, and graphics displays.

Enhancement requests were presented to Computervision. Due to the complexity of the changes required to meet our requirements, Computervision was unable to implement the changes within the timeframe required for this project. Consequently, implementation of the "Electronic Distribution Cell" at this time is not recommended, but rather, that the technology be submitted for further study and development. This item will be discussed further under Section 17, Areas for Future Concerns/ Development in this report.

4. Set-up Optimization for Automatic Insertion Cell

BACKGROUND

Initial CBA data revealed that the set-up times required for installing the reels of axial components and tubes of DIP components are perhaps more labor intensive (i.e. more time consuming for low quantity runs of boards) than the actual inserting of the components themselves. Since all the component insertion information for all of the PWA's will be generated in the "Create Process Cell" and will reside in the CADDSERVER system storage, it is feasible to optimize the machine set-ups based on commonalty between different PWA's.

APPROACH

Due to the unique requirements for the "Set-up Optimization for Automatic Insertion Cell" in the PWA factory, it was determined that internally developed software would be the best approach. Prototype optimization software was developed during the Phase 2 effort, which verified this approach. The software performs the following functions:

1. Performs real time simulations based on the PWA assembly choices input by the engineer and groups the PWA's with common parts into family set-ups.
2. Generates a set-up list defining the component part numbers and their reel/channel locations for the set-up person.
3. Automatically edits the machine programs to call out the appropriate reel/channel location instructions for the inserter based on the optimized set-up.

The prototype optimizer software was written in the "C" language and developed on a PC-AT computer. During Phase 3 implementation, the software will be ported to the CADDSERVER platform.

5. Machine Interface Cell

BACKGROUND

The objective of the "Machine Interface Cell" is to eliminate all the individual "floppy disk" programs for the PWA factory equipment.

APPROACH

The Machine Interface module of Computervision's Factoryvision software was selected to perform this function. The "Machine Interface Cell" will perform the following functions:

1. Provide user definable communication lines and protocol for the machine host interface. The communication lines between host and machine will be RS-232 lines connected into the CADDSERVER's multiplexor.
2. Provide links between the Universal and CS-400B insertion machines and the host CADDSERVER. The communications are bi-directional between host and machine, so that in addition to the program download from host to machine, programs with coordinate modifications performed on the machine can be sent back to the host for future use without remodification.
3. Provide host storage for all the machine programs for the PWA factory assembly equipment.

SUMMARY

The approaches taken for the "Create Process Cell", the "Storage and Control Cell", the "Set-up Optimization for Automatic Insertion Cell", and the "Machine Interface Cell" provide the necessary integration between the four functions. In addition, the "Create Process Cell" will be closely integrated with the CAD data base environment. The functional software for all cells will be hosted on the Computervision CADDSERVER platform.

SECTION 4

"AS-IS" PROCESS

The "As-Is" Process environment for Project 32 was the Honeywell Military Avionics Division, Flight System Operations, Printed Wiring Assembly (PWA) Production Facility. This facility is located in St. Louis Park, Minnesota. The PWA Facility assemblies, solders, in-circuit tests, and conformal coats Printed Wiring Assemblies to various military specifications. It is a medium mix medium volume military production facility that produces Printed Wiring Assemblies for a wide variety of "black boxes" used in a diversity of airframes.

The PWA production facility consists of 80 operator workstations arranged along an automated material handling system that also schedules and prioritizes work for the operator workstations (Figure 4.1).

The Production Engineering office is adjacent to the manufacturing facility. The Production Engineering Department is responsible for determining the processes by which the PWA's will be built, generating the detailed production process instructions for the PWA's, generating the numerical control (NC) program instructions for factory assembly equipment, controlling the production process instructions and NC programs, and assuring that the production process instructions and NC programs are distributed to the factory in a timely manner (Figure 4.2).

Project 32 deals with these functions as five cells which are defined as follows:

1. "Create Process Cell"
2. "Storage and Control Cell"
3. "Electronic Distribution Cell"
4. "Set-up Optimization for Automatic Insertion Cell"
5. "Machine Interface Cell"

The "As-Is" process for these five project cells will be discussed in detail below.

1. Create Process Cell

When creating a process for a PWA, the Production Engineer must first develop a strategy for populating the PWA's components. The methods typically utilized for populating PWA's are automatic insertion, semi-automatic insertion, and hand assembly.

Working with design documentation for the PWA (assembly prints and parts lists), the Production Engineer must review each component (typically 200-300 are on a PWA) to determine which assembly method should be utilized to attach the components to the PWA.

The Production Engineer first reviews each component to determine if it can be automatically inserted. The PWA factory utilizes two pieces of automatic insertion equipment: the first, an axial part inserter, is a Universal VCD/Sequence Inserter Model 6241A, and the second, a Dual Inline Package (DIP) Inserter, is a Universal DIP Multi-Module Inserter Model 6772A. Physical features of the parts such as body size and lead diameter in conjunction with layout features of the PWA such as tooling holes and other part obstructions, determine if each component can be assembled automatically (Figure 4.3).

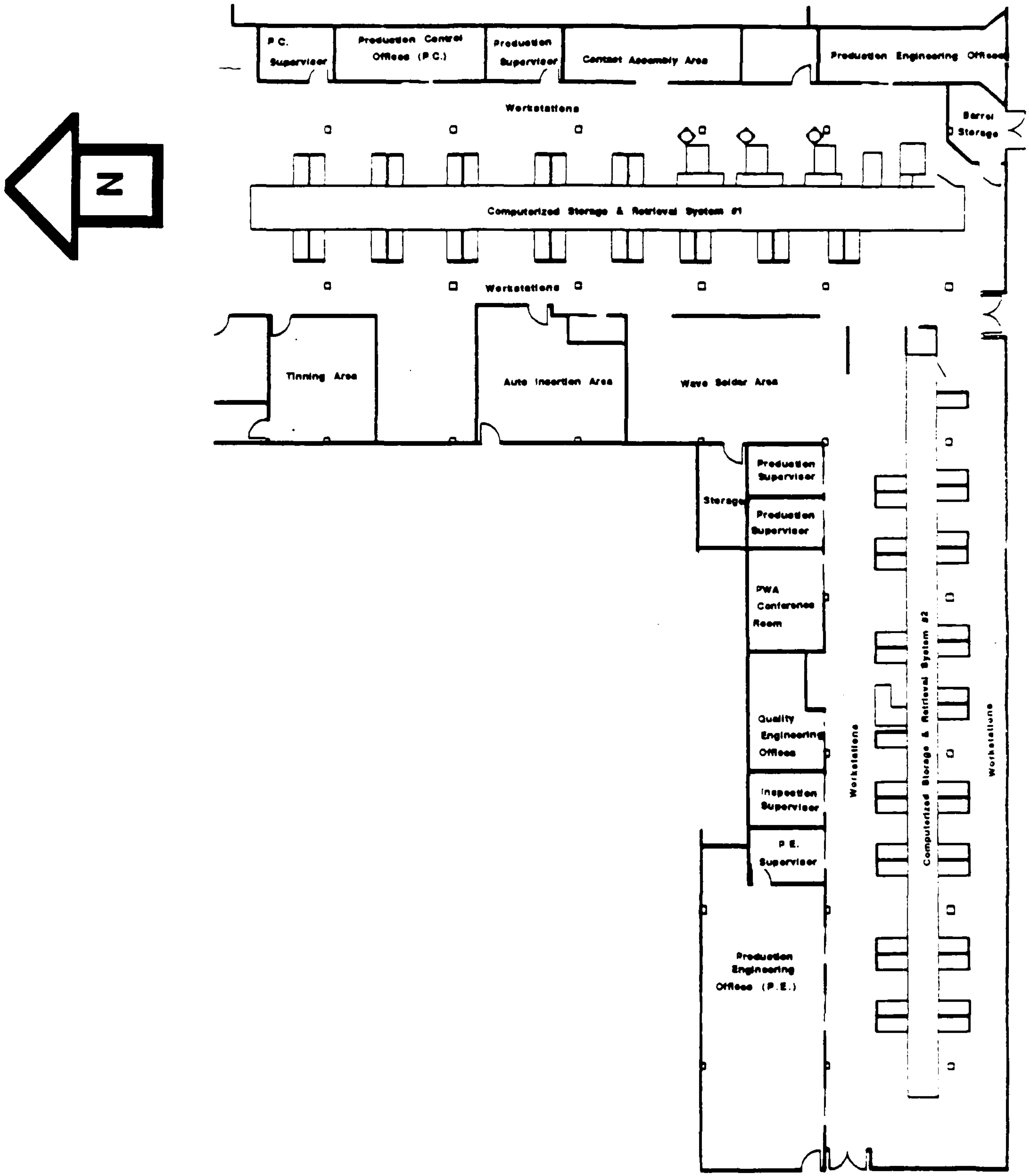


FIGURE 4.1 PWA LAYOUT "AS-IS"

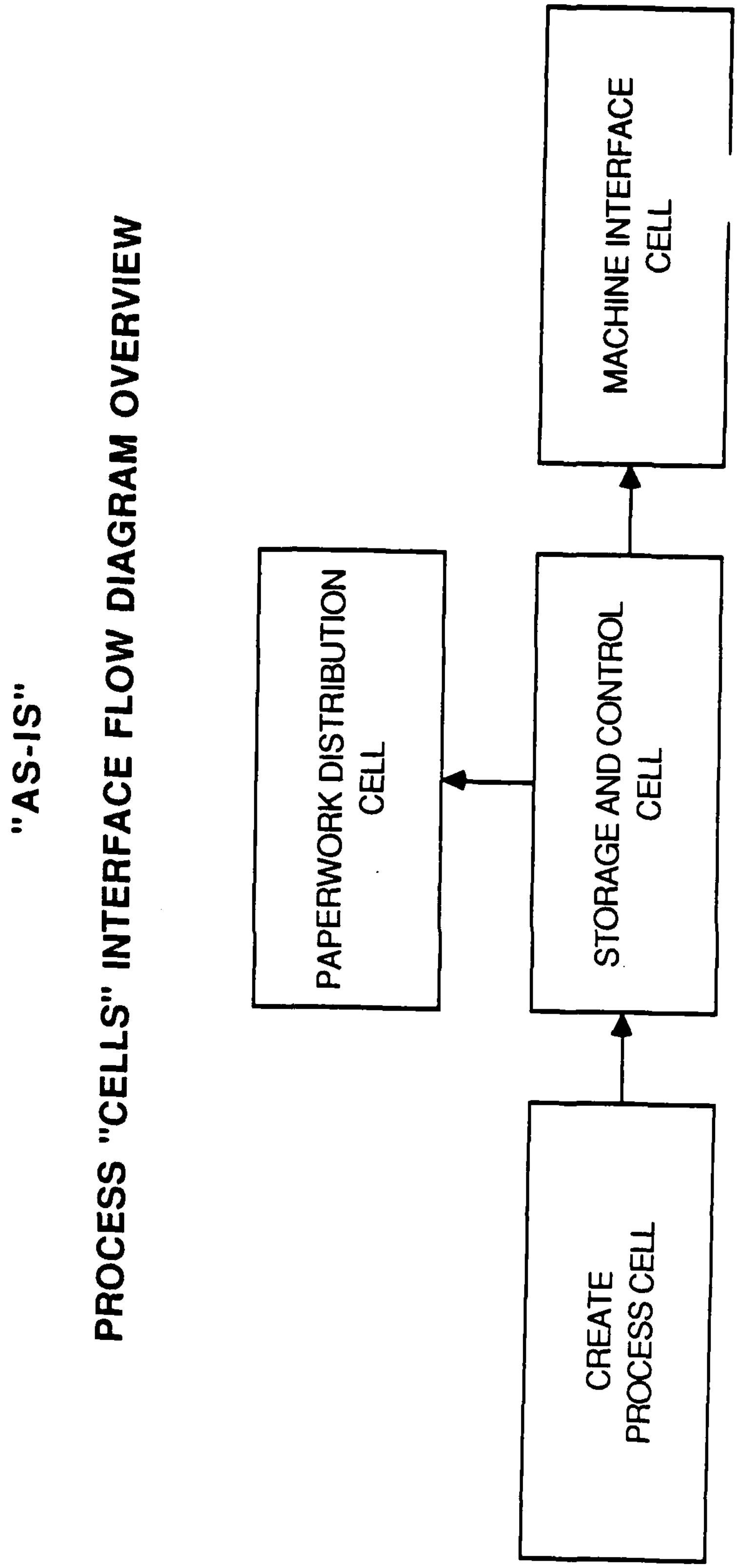


Figure 4.2 "AS-IS" PROCESS "CELLS" INTERFACE FLOW DIAGRAM OVERVIEW

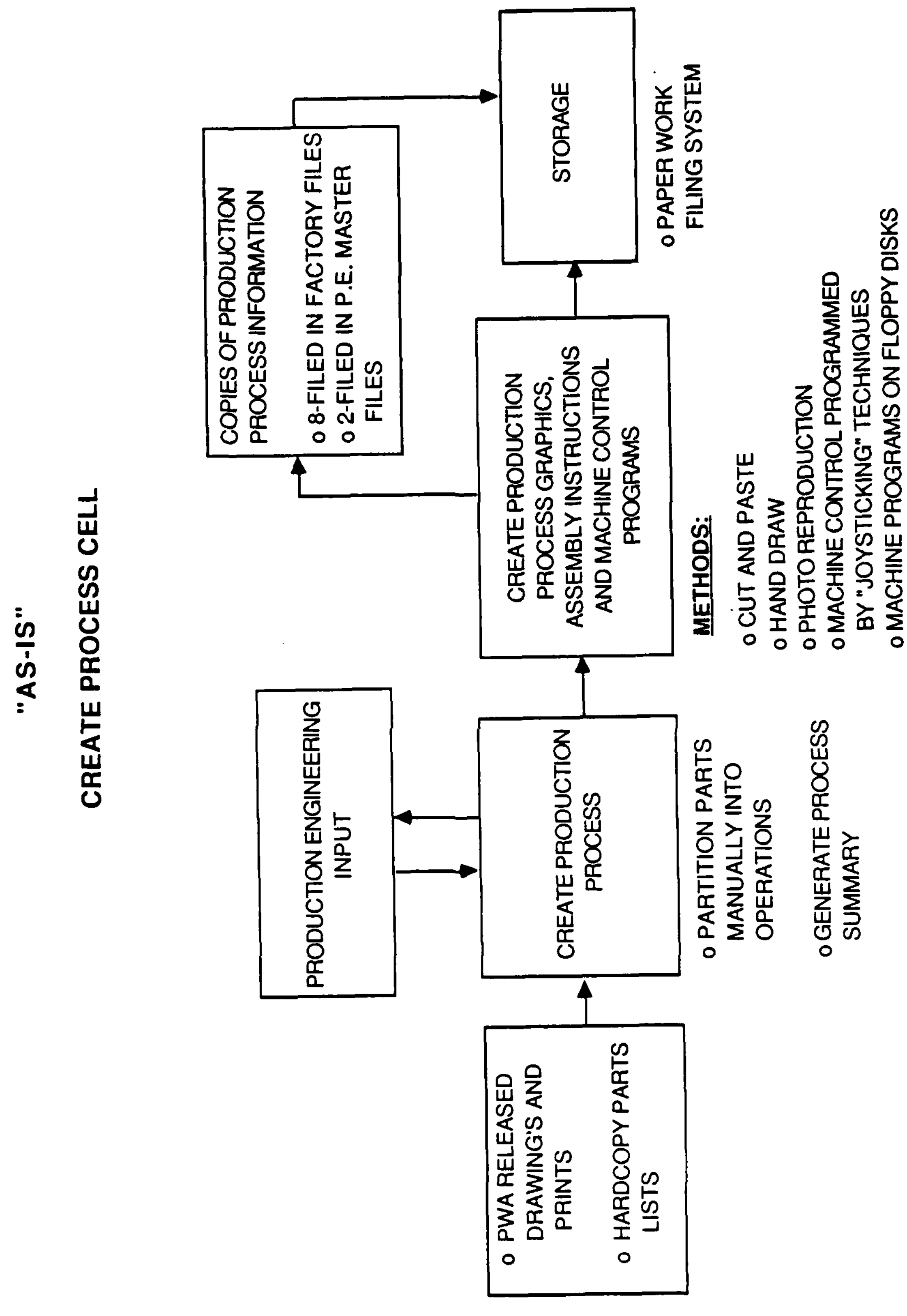


FIGURE 4.3 "AS-IS" CREATE PROCESS CELL

The remaining parts which can not be assembled automatically are reviewed to determine if they can be assembled semi-automatically on a Contact Systems CS400-B. The CS400-B aids the operator in assembling the components by rotating a parts carousel to present the appropriate part and by projecting an overhead light onto the PWA to show the part's position and polarity. The Production Engineer will usually plan for radial leaded parts and parts which can not be automatically inserted to be assembled using the CS400-B machines.

Parts which can not be assembled on the Universal automatic insertion equipment or the Contact Systems CS400-B are planned for either a pre-wave soldering hand assembly operation, or a post-wave soldering hand assembly operation.

After partitioning all the PWA's components into the appropriate assembly operations, a Process Summary is input to the Process Management System (PMS) Computer. Each component part-number, its item type, description, reference designator call-out, and usage quantity must be input to the PMS computer.

Next, the Production Engineer creates the Process Detail (detail drawings) for shop floor use. The Process Detail drawings are basically manually generated: hand drawings and/or cut-and-paste methods are typically used. In some cases, PWA artwork must be photographically enlarged, reduced, and/or mirrored to generate the required drawings. For certain operations, Production Engineers may enhance the detail drawings with colored pencils.

The Production Engineer must then create NC machine programs for the Universal automatic inserters and the CS400-B machines. The Production Engineer must determine the appropriate assembly sequence for each part which he wants in the program. The machines rely on instructions containing coordinate information, so the appropriate coordinates must be determined and added to the program. Typically, in order to determine the coordinates for a PWA program, the CS400-B and the Universal inserter had to be taken out of production mode, and "joysticking" techniques used to manually drive the machine to the appropriate locations for coordinate recording. For axial insertion programs, head-spans (the distance between component lead holes plus an adjustment for lead diameter) and depth stops (based on body diameter and lead diameter) must be input for each part to be inserted. The resultant programs for the Universal inserters and the CS400-B are contained on floppy disks.

For both axial and DIP insertion, set-up lists must be generated that define from which reel location (for axial) and tube location (for DIPS) each part is to be dispensed. For CS400-B and hand build operations, Kitting/Staging lists must be generated which include each part-number callout, the bin where the part is located, quantity usage, and reference designator callout.

Inefficiencies of the"As-Is" "Create Process Cell" are:

1. The time required for the Production Engineer to manually partition all the components into their appropriate assembly operations.

2. Each Production Engineer has "his/her way" of presenting the process detail information, i.e. components to be inserted are highlighted in different ways, the sequence of insertion is different etc. As a result, the assembly operator is confronted with inconsistent instructions from one PWA job order to the next.

3. Information, both text and graphics, is re-transcribed multiple times throughout the job of creating the Process Summary and Process Detail. For example, component part-numbers are entered into the Process Summary, and also may be contained in NC set-up lists and program listings, Kitting/Staging lists, and in Process Detail graphics. The opportunity for error is significant.

4. Information for Universal automatic insertion programs, such as depth stop and head-span data has to be repeatedly looked up in reference documents.

5. When "joysticking" techniques are used to obtain coordinates for Universal automatic insertion programs and CS400-B programs, machine utilization is impacted adversely since the machines have to be taken out of production mode.

2. Storage and Control Cell

After release of the process, ten copies of the PMS Process Summary are delivered to PWA Production Engineering. Ten copies of the Process Detail are ordered from the copy center, and when received, combined with the Process Summary. Average turnaround is one day for the copies, or in the case of color reproductions, two days. Eight copies are sent to the floor, one copy is filed by the Production Engineer, and one copy is filed in the Production master file. When changes to any of the process information are made, all the previous revision processes must be retrieved and destroyed, and a complete new package of both Process Summary and Process Details is issued.

A master disk for each CS400-B program and each Universal automatic insertion program is retained in Production Engineering files and a disk copy is stored on the shop floor. When a change in process is made, Production Engineers must revise the program, update both the master disk and the shop floor copy, re-label with the new issue, and update the Process Detail to reflect the change.

Inefficiencies of the "As-Is" "Storage and Control Cell" are:

1. Turn-around time for getting Process Summaries and Process Details into the system.

2. Copy costs of the documentation.

3. Retrieval of old process data when a new revision is issued.

4. Control of NC programs on floppy disks.

5. A complete package of both Process Summary and Process Detail is issued whenever a change to any part of the process is made.

3. Electronic Distribution Cell

The present system is basically a paper-based system. When job orders are issued to the floor, two copies of the Process Summary and Process Detail package are issued with each job order. An order normally consists of up to 15 PWA's. If an in-process inventory is larger than 60 PWA's, then additional copies must be made from the master. The Process Summary and Process Detail package is delivered to the assembly operator in the tote along with the parts by the automated material handling system (Figure 4.4).

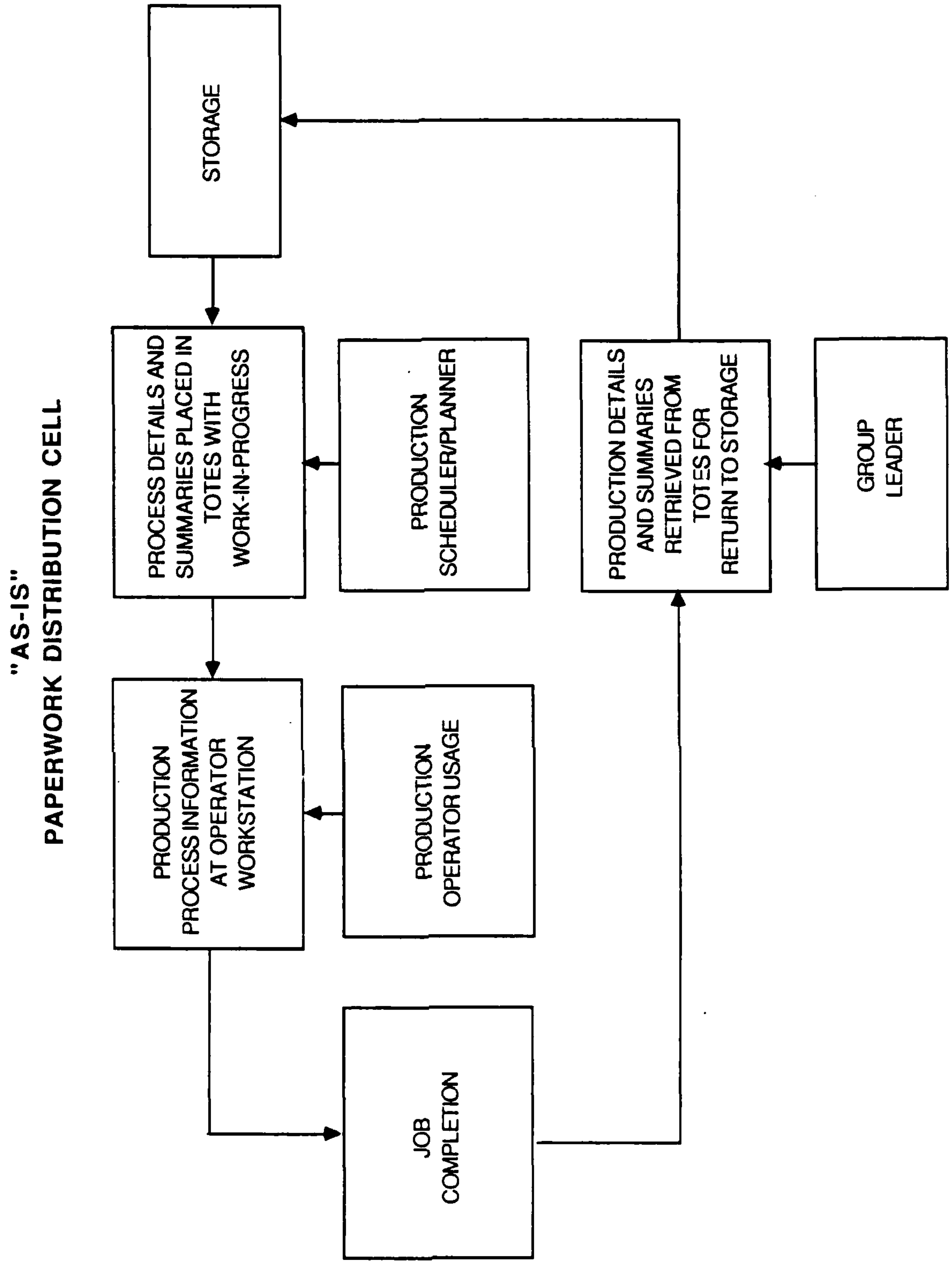


FIGURE 4.4 "AS-IS" PAPERWORK DISTRIBUTION CELL

Inefficiencies of the "As-Is" "Distribution Cell" are:

1. The large volume of paper that is in the system.

2. Difficulty with purging old process information from the distribution system when changes are made and new process information is issued.

4. Set-Up Optimization For Automatic Insertion Cell

Project 32 identified the set-up for automatic insertion as a significant cost driver, since, in the As-Is" condition, the set-ups are done on a single PWA basis. That is, any form of optimizing is non-existent. After a job order is run for a given PWA, the component reels and tubes are torn down before the next PWA job order is run. Set-up times are typically longer than the actual times of insertion. The concept of optimizing the set-up across a family of PWA's would save significant set-up time, but millions of calculations are required to perform the optimization function for a family of PWA's and to modify the individual PWA insertion programs to call out the appropriate reel/tube for a common set-up.

Inefficiencies of the "As-Is" "Set-up Optimization for Automatic Insertion Cell" are:

1. Set-up times are as long if not longer than the actual run times for a job order.

2. Automatic insertion machines must be taken out of a production mode to perform the set-up operations causing machine utilization to be adversely impacted.

5. Machine Interface Cell

The "As-Is" interface with the Universal automatic insertion equipment and the CS-400B is through floppy disk media. On the shop floor, a set-up person is responsible for setting up the machines. The set-up person must look at the Process Detail to determine the appropriate issue disk to use for the job order. The appropriate floppy disk must be retrieved from the shop floor file, installed on the machine, and adjustments made. When the job order is complete, the floppy disk must be retrieved from the machine by the set-up person and returned to the shop floor file (Figure 4.5).

Inefficiencies of the "As-Is " "Machine Interface Cell" are:

1. Determination of and retrieval of proper issue of floppy disk program by the set-up person.

2. Maintenance of floppy disk storage system.

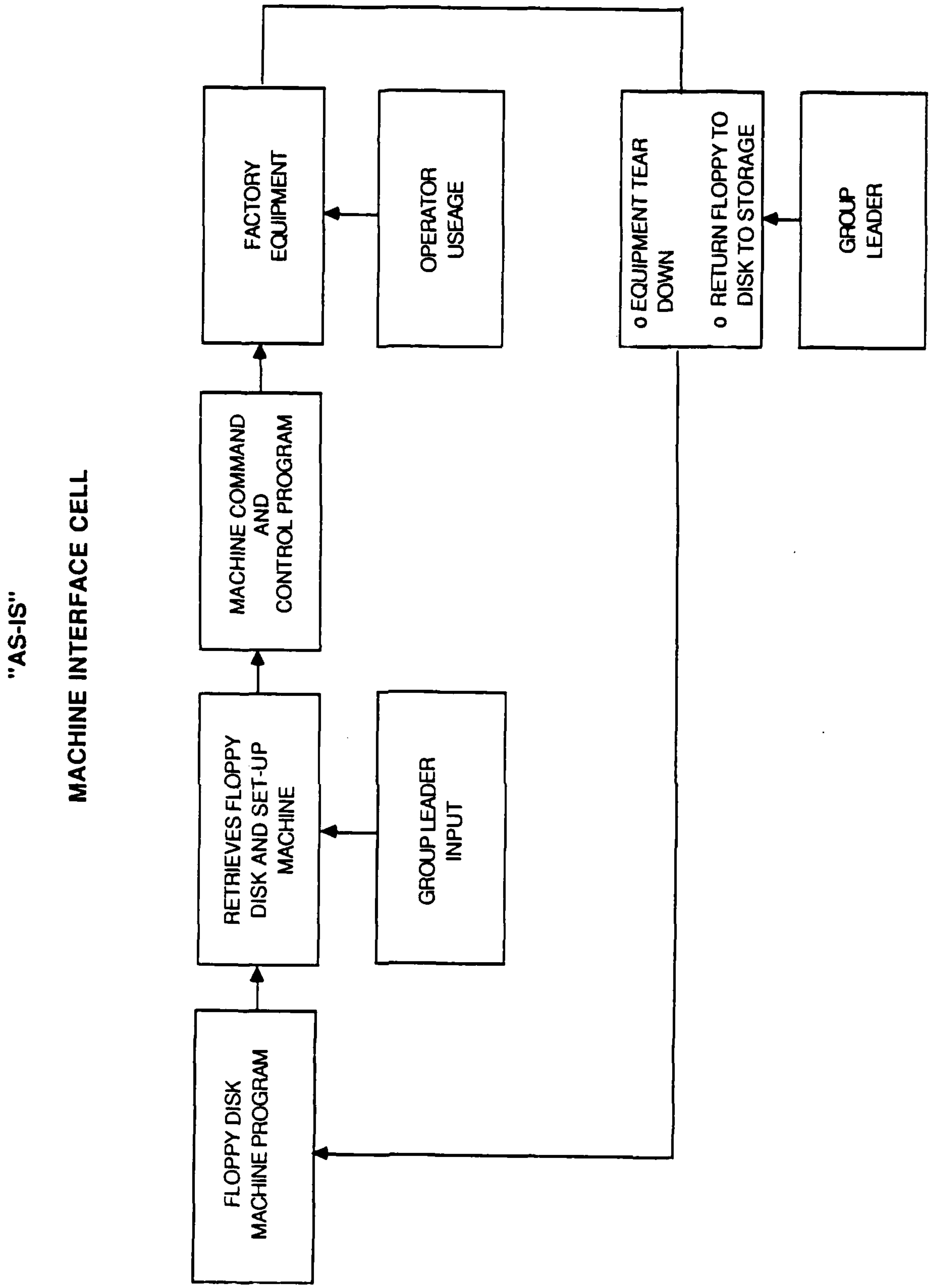


FIGURE 4.5 "AS-IS" MACHINE INTERFACE CELL

SECTION 5

"TO-BE" PROCESS

The "To-Be" process environment and factory pilot test bed for Project 32 Factoryvision was the Honeywell Military Avionics Division's (MAvD) Flight System Operations(FSO), Printed Wiring Assembly (PWA) Production Facility. This facility is located in St. Louis Park, Minnesota, a suburb of Minneapolis. The PWA Facility assemblies, solders, in-circuit tests, and conformal coats circuit card assemblies to various military specifications. The PWA facility is a medium mix medium volume military Production Facility that produces circuit card assemblies for a variety of "black boxes" used in a diversity of military airframes. This PWA Production Facility consists of 80 operator workstations arranged along an automated material handling system that also schedules and prioritizes work for the operator workstations.

No facilities layout changes will occur to the operator workstations or the automated material handling system as a result of implementation of the "To-Be" Process System of Project 32 Factoryvision. A room approximately 20 feet by 18 feet will be required next to the Production Engineering office area which is adjacent to the manufacturing facility. This new room will house the three Production Engineer Workstations and the Fileserver (Figure 5.1 & 5.1A).

Considerations for the choice of location for this room were dictated mainly by accessibility of this equipment to the majority of users, the Production Engineers, and to a lesser degree by the interface cabling route and length considerations.

The "To-Be" System of Project 32 Factoryvision will integrate CAD, CAM, and factory management techniques to create, store and control, and distribute factory product information in a real time environment (Figure 5.2). Only recently, through the advent of decreasing costs of micro processors, memory, and peripherals, has it become economically feasible to utilize engineering workstations to manipulate CAD data base information and create production process information, then distribute on a real time basis electronically to the factory floor instead of relying on hand carried paper.

The migration of information from the CAD data base into CAM production process information by this system will be the first of two steps the "To-Be" Process has been divided into. The second step will address the electronic control, distribution, and display of this CAM produced production process information.

STEP 1

The first step of this system will expand the value of CAD/CAM information by enabling the Production Engineer to derive production process graphics, add production textual process instructions, and generate machine control programs from the CAD data base. This manipulation of the CAD information will be done by Production Engineers on high-powered engineering workstations and will be discussed in the "Create Process Cell" and "Set-up Optimization for Automatic Insertion Cell".

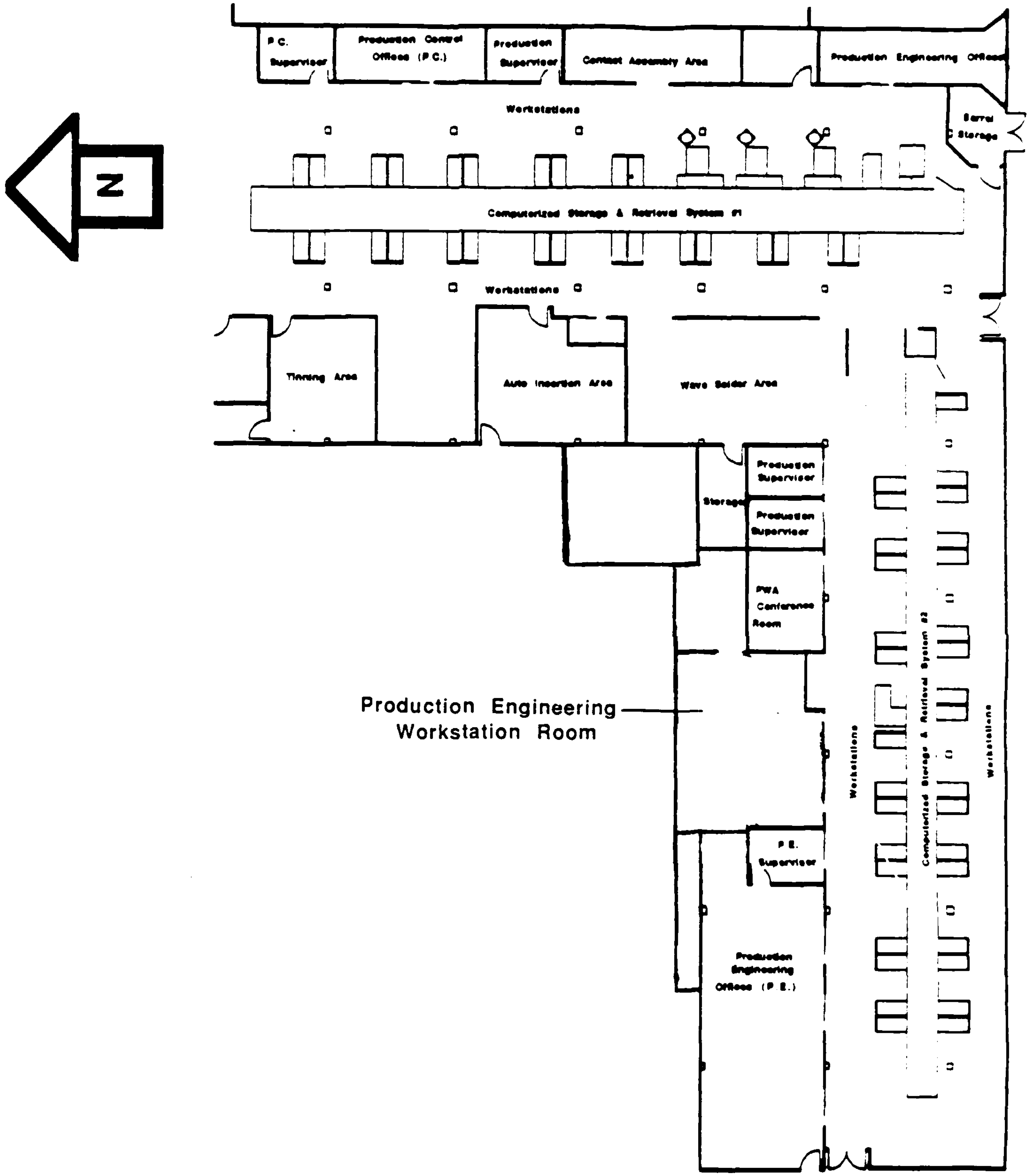
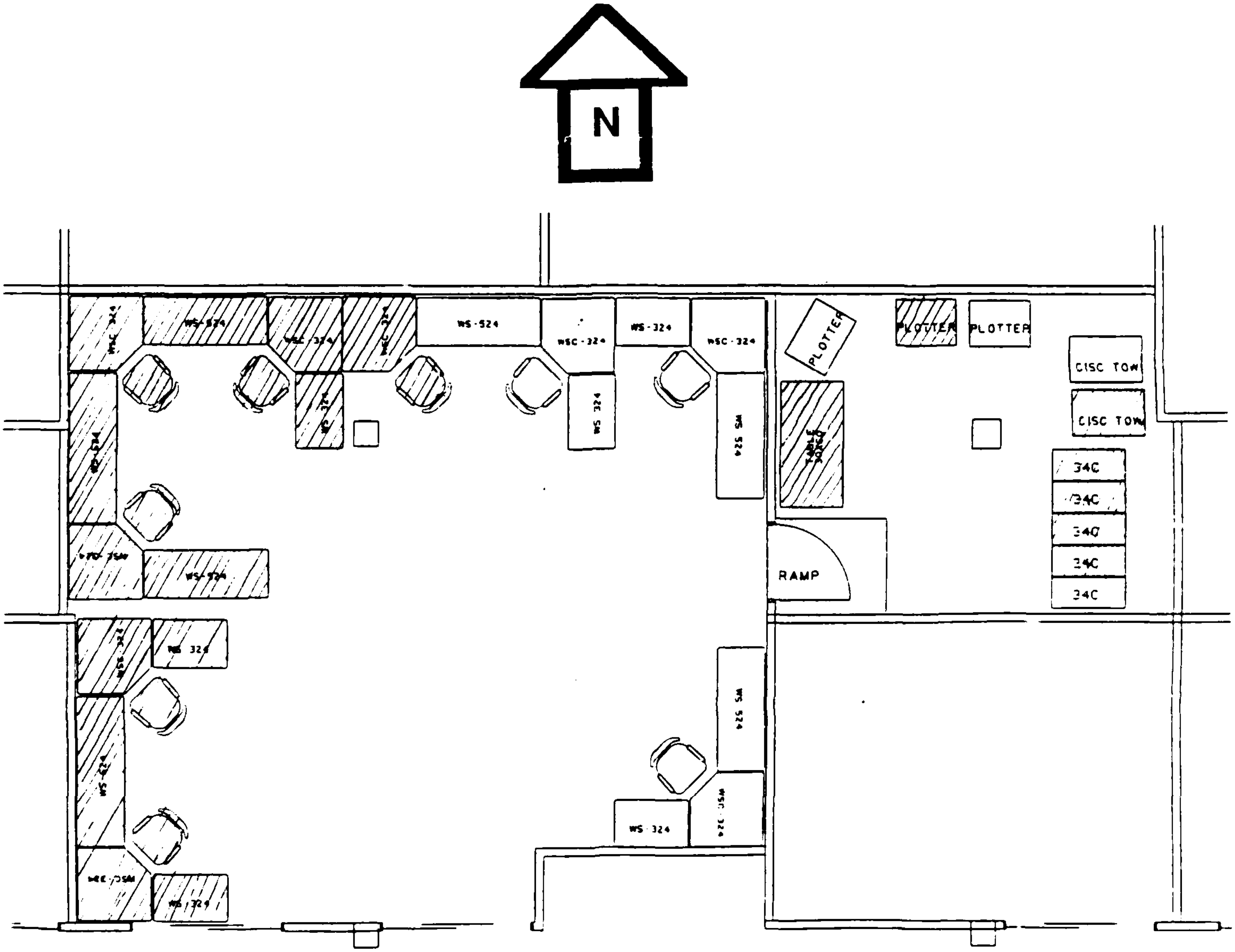


FIGURE 5.1 PWA LAYOUT "TO-BE"



NOTE: The stripped areas are part of the fifth cell (Electronic Distribution Cell) and are not going to be implemented at this time. The Electronic Distribution Cell will be implemented when it is technically achievable.

FIGURE 5.1A PRODUCTION ENGINEER WORKSTATION ROOM

"TO-BE"

PROCESS "CELLS" INTERFACE FLOW DIAGRAM OVERVIEW

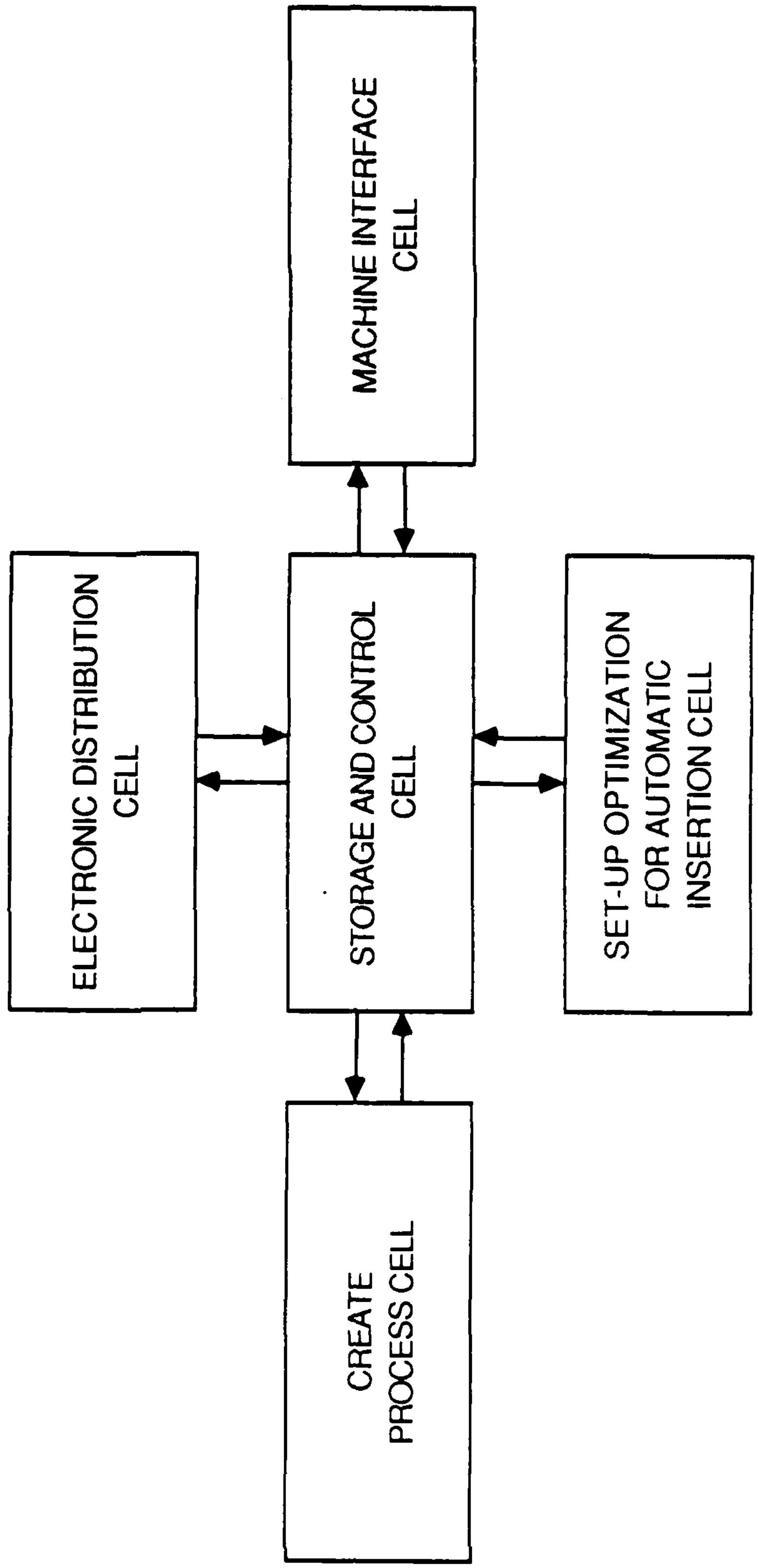


FIGURE 5.2 "TO-BE" PROCESS "CELLS" INTERFACE FLOW DIAGRAM OVERVIEW

Create Process Cell

In order to electronically display the production process information required by the factory at the operator workstations, it was determined that standardization of format of this production process information must first be instituted. To accomplish this, and also to significantly reduce the large amount of time and effort required by Production Engineers to create production process information for new products and to change or amend current or historical production process information, Honeywell MAvD developed a in-house software application. This software application, consisting of many software programs, will be exercised on high-powered Production Engineering Workstations utilizing 68020 micro processors running the UNIX operating system and has been named the "Create Production Process Program". Basically, what this software application does is take already existing information pertaining to a PWA in the CAD data base and manipulates this information to user specified formats and parameters using predetermined subroutines and library programs (Figure 5.3).

The type and format of the production process information, or in some instances data, that this software application yields is dependent on the production process/operation specified. All of the production operations performed in the PWA area have been categorized into four major operations: Automatic Insertion Operations, Semi-Automatic Insertion Operations, Hand Build/After Wave Solder Assembly Operations, and Miscellaneous Operations.

1. Automatic Insertion Operations

The PWA facility utilizes two pieces of automatic insertion equipment; the first, an axial style component inserter, is a Universal VCD/Sequence Inserter Model 6241A, the second, a Dual Inline Package (DIP) style component inserter, is a Universal DIP Multi-Module inserter Model 6772A.

When the Production Engineer specifies the Automatic Insertion Operation parameter in the "Create Production Process Program" the program will automatically generate the automatic insertion equipment's command and control programs for both the axial and DIP style components. Also included are tool plate requirements, tool path and set-up graphics, assignment of part numbers to reel and channel locations, and other pertinent set-up instructions.

2. Semi-Automatic Insertion Operations

The PWA Facility has a Contact System's CS400-B Component Locater as its primary piece of semi-automatic insertion equipment.

If the Production Engineer specifies the Semi-Automatic Insertion Operation parameter in the "Create Production Process Program", the program automatically generates the semi-automatic insertion equipment's command and control program along with set-up graphics, assignment of components to bins, tool plate requirements, and all supplemental assembly graphics and text instructions.

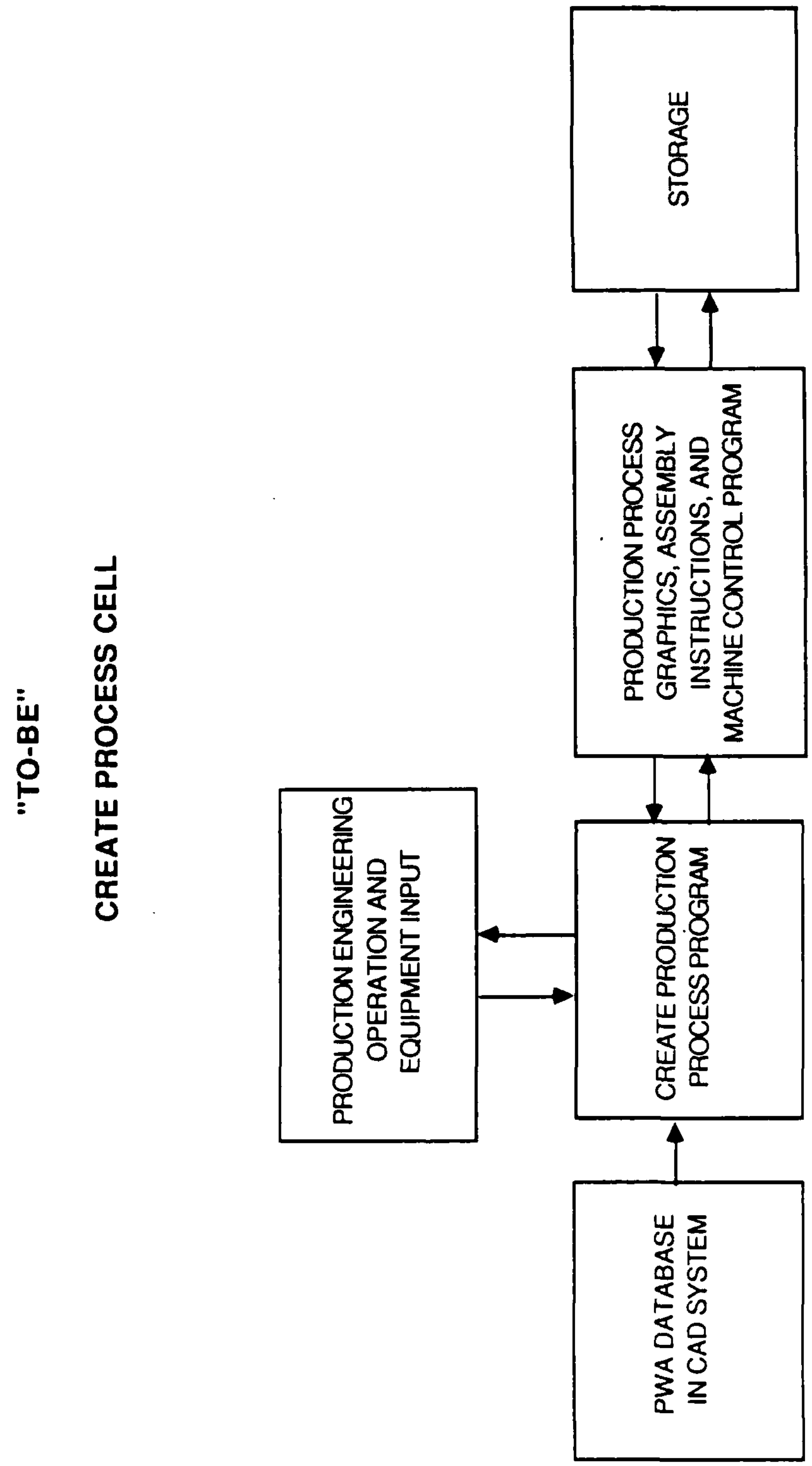


FIGURE 5.3 "TO-BE" CREATE PROCESS CELL

At this point in the creation of the Production Process Sequence all of the components that meet the criteria for automatic and semi-automatic insertion have been partitioned into those operations. All the remaining components of the PWA must be accounted for in the Hand Build/After Wave Solder Assembly Operations or the Miscellaneous Operations. Predetermined component library parameters and Production Engineering inputs into the "Create Production Process Program", dictate into which of these operations the components are partitioned.

3. Hand Build/After Wave Solder Assembly Operations

For Hand Build/After Wave Solder Assembly Operations the "Create Production Process Program" will automatically generate a sequence of graphics pages (in paper mode), or graphics screens (in the electronic display modes). Color discrimination coding will be used in these sequences to show the background circuit board with tracks and pads, the components being assembled in the present sequence, and the components which have been assembled in previous sequences. Caution notes and standard instructions will be extracted from libraries resident on the engineering workstation platform and added to assembly graphics and text

4. Miscellaneous Operations

For Miscellaneous Operations the "Create Production Process Program", in association with Production Engineering inputs, will generate high quality exploded graphics views, PWA backside views, and add actual color, color coding, and color discrimination whenever possible or required. The "Create Production Process Program" has defined miscellaneous operations as production operations such as; Jumper Wire Assembly, Connector Assembly, Stamping, Masking, Wave Solder, Conformal Coating, Cleaning, In-circuit Testing and Repair Processes.

The procedure for the Production Engineer to use the "Create Production Process Program" will be accomplished by using the high-powered engineering workstations to access the Engineering ETHERNET system to retrieve the PWA data base information resident on the CAD system. After accessing the CAD system the Production Engineer will make a copy of the PWA data base file and transfer this copy, through the ETHERNET interface, to the production engineering workstation. Once the file has been transferred, it will be manipulated by CAM software (the "Create Production Process Program"), resident on the workstation, to derive shop floor process graphics, process instructions, and machine command and control programs.

The Production Engineer, using the highly interactive tutorial software, will define the operations and insertion equipment to be used in the production process.

After creation, the process instructions with graphics and machine command and control program will be reviewed, signed-off, and then automatically transferred to the "Storage and Control Cell" of the "To-Be" Process System.

Set-Up Optimization for Automatic Insertion Cell

Now that the automatic insertion equipment command and control programs for both axial and DIP style components have been created by the "Creation of Process Cell", and are stored in the "To-Be" Process System memory which is resident on the Fileserver of the "Storage and Control Cell", a second piece of Honeywell developed software can be utilized. This software application will increase the efficiency of the automatic insertion equipment workstations, drastically improve the machine utilization ratios, decrease the through-put times of product at these workstations, and reduce machine set-up time by a minimum of one-third. This powerful piece of software has been named the "Automatic Insertion Equipment Set-up Optimization and Machine Control Program" (Figure 5.4).

In order to understand how this program can provide all of these benefits, it must be realized that because of the extremely large number of components that the automatic insertion equipment can insert into an assembly in a small period of time, the set-up times required for installing the reels of axial style components and tubes of DIP style components are more labor intensive than the actual inserting of the components.

In addition, the product mix consists of thousands of different PWA's with low annual volumes. However, the design of these PWA's, is perfectly suited for automatic insertion techniques. In order to solve the problem of efficiently and cost effectively automatically inserting this low volume yet large product mix of PWA's, a method was developed to "Group Run" different Printed Wiring Assemblies with a common set-up. This optimized set-up is generated by the "Automatic Insertion Equipment Set-up Optimization and Machine Control Program".

This program is able to function in the "To-Be" Process system because all component insertion information for all of the PWA's has been stored in disk storage, on the Fileserver of the "Storage and Control Cell". It now becomes possible to optimize the machine set-ups based on component commonality between different PWA's by accessing and utilizing the set-up optimization software capabilities that reside on the "To-Be" Process System.

The "Automatic Insertion Equipment Set-up Optimization and Machine Control Program" generation software will run real time set-up simulations based on the assembly part numbers and choices input by the machine operator. From these simulations, the PWA's with common parts will be grouped into common set-ups. These common set-ups are referred to as Optimized Set-ups.

After the application software has determined the Optimized Set-up for a given set of PWA's the program will then set-up staging lists, assign reel and channel locations on the inserters, and edit the numerical machine command and control programs to call out reel/channel locations for that particular Optimized Set-up. All set-up information, program listings, etc. will be available through the shop floor terminals located at the Auto-Insertion equipment workcenters. A printer at the shop floor workstation terminal will make hard copies of any information when deemed necessary.

Set-up Optimization for Automatic Insertion Cell Utilization Procedure

To utilize the set-up optimization software, the machine operator will use the wand of a bar code reader to enter the system through the Machine Interface Cell. Once admitted to the system, one of the choices available to the machine operator on the machine interface menu will be for set-up optimization. By choosing this option, the machine operator will generate the optimum set-up or set-ups for the PWA's to be auto-inserted on that particular day. This optimum set-up will be generated by the interactive "Automatic Insertion Equipment Set-up Optimization and Machine Control Program" resident in the "Storage and Control Cell" and simple inputs from the machine operator. These inputs will consist of "canned" choices and entry of assembly part numbers when prompted by the application software through the miniaturized keyboard at the factory floor workstation terminal.

"TO-BE"
SET-UP OPTIMIZATION FOR AUTOMATIC INSERTION CELL

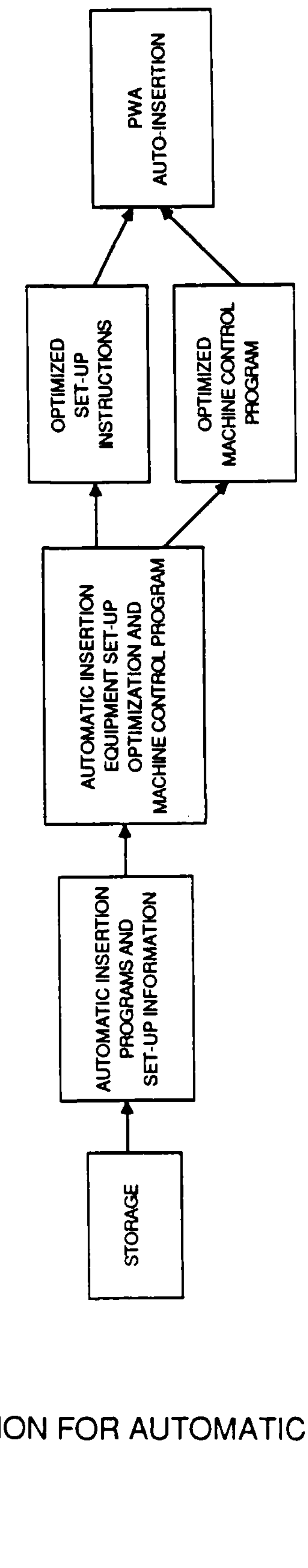


FIGURE 5.4 "TO-BE" OPTIMIZATION FOR AUTOMATIC INSERTION CELL

STEP 2

The second section of the "To-Be" Process will address the storage, control and distribution of production process graphics and assembly instructions and numerical data to operator workstations throughout a network of factory floor workstation graphics terminals. The production process graphics and assembly instructions will be discussed in the Electronic Distribution Cell, while the electronic data transfer interface techniques will be explained in the Machine Interface Cell.

Storage and Control Cell

Each Storage and Control Cell (the System Fileserver in the "To-Be" Process) will be capable of storing about two gigabytes of data and production process information. Modularized software, resident on the Fileserver, will perform many workcenter administration and control functions. The Fileserver will assure that all the process information (text, graphics, common operating details, machine control programs, etc.) exists on the system for a given operation at a given workcenter and that the revision letter and issue number of all process information are correct. The Fileserver will have the capability to control and distribute process information for multiple revisions and issues of the same PWA number, by job order, when different revisions or issues of the same PWA are being produced during the same time period.

Electronic Distribution Cell

After the production process graphics and instructions have been created on the engineering workstation, and cataloged in the storage and control fileserver of the "To-Be" system, they will be available for distribution to any of the factory floor workstations.

At each of the factory floor workstations, there will be a 13 inch color CRT shop floor terminal, a bar code reader, foot pedal, and a miniaturized key pad. This equipment will comprise the factory operator's interface in to the "To-Be" System. Through this interface the factory operator will receive all process graphics and instructions required to build, test, and inspect all PWA's produced within the PWA Facility (Figure 5.5).

Electronic Distribution Cell Utilization Procedure

For the system to be activated, the operator will use a bar code reader's wand to enter identification information into the system. If the operator is not certified for performing the tasks at that workcenter, the computer in the storage and control cell will not allow access to the process instructions. The operator certification information will be entered into the Storage and Control Cell Fileserver by the factory clerk, through an engineering workstation from operator personal records. Once identification information has been checked and found to be correct for the tasks being performed, the operator is admitted to the system. At this time the operator will then wand the bar code label on the traveler for the operation to be performed. This will immediately cause the appropriate issue and revision of the process graphics and instructions to be displayed on the operator factory floor terminal. The operator will use the foot pedal to change the displayed screens of the pre-established sequence of instructions and also use the miniaturized keyboard to enter assembly configuration data such as component lot numbers and serial numbers when prompted and access the "HELP" screens.
Note: This cell is not going to be implemented due to technical & software limitation & at the present time a plotter will be connected to the Storage and Control File Server which will generate interim paper plots and will be copied and distributed as in the "As-Is" Electronic Distribution Cell.

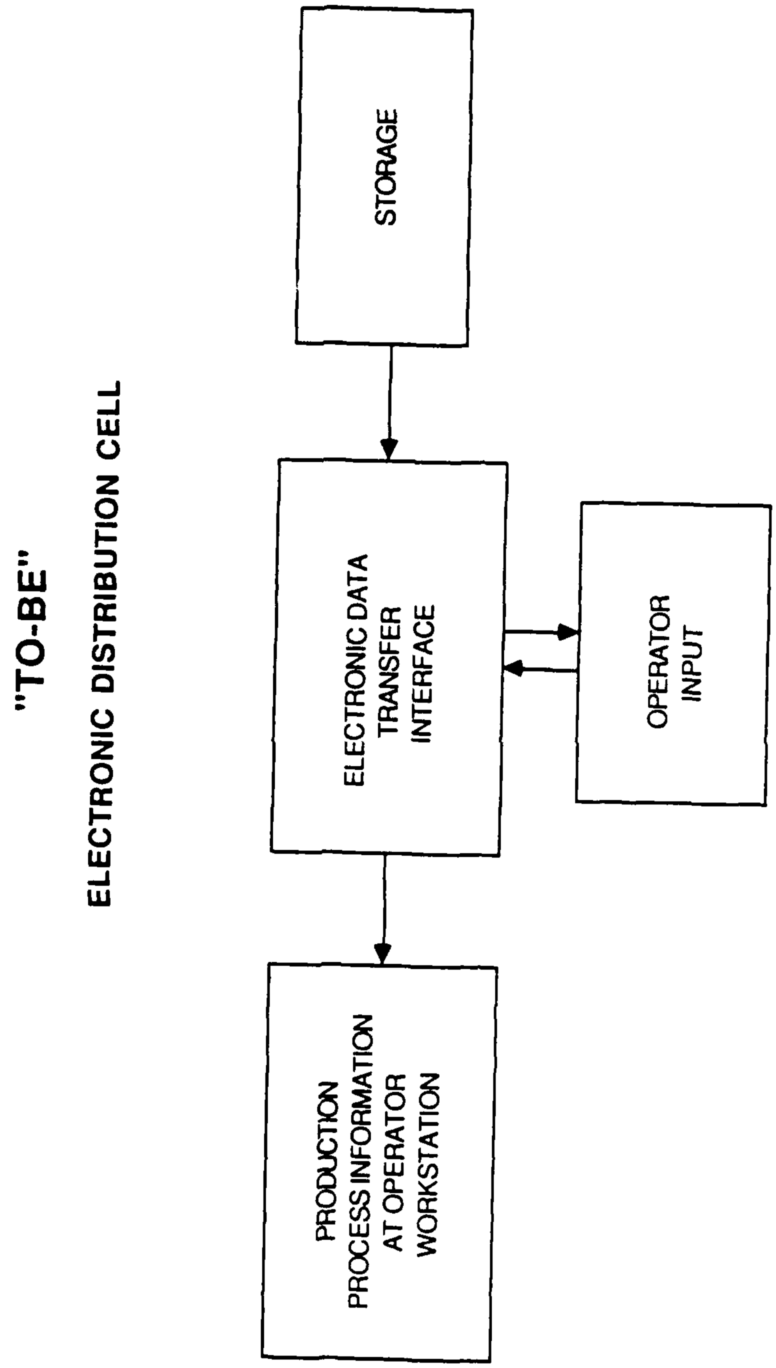


FIGURE 5.5 "TO-BE" ELECTRONIC DISTRIBUTION CELL

Machine Interface Cell

The Universal automatic insertion equipment and the Contact System's CS400-B semi-automatic insertion equipment will be directly interfaced linked, to the "Storage and Control Cell" fileserver of the "To-Be" Process System through a port on the same factory floor workstation terminals used to present production process graphics and instructions. This is possible because machine set-up instructions and graphics, and machine command and control program downloads are performed prior to the start of actual production assembly processes. Utilizing one factory floor workstation terminal to perform two functions is also beneficial by saving the space at the workstation required by a second terminal and by saving the costs associated with a second terminal (Figure 5.6).

Machine Interface Cell Utilization Procedure

To use the electronic data interface provided by the Machine Interface Cell to transfer data to any piece of equipment on the system, the machine operator will use the wand of a bar code reader at the workstation terminal to enter identification information into the system. If the machine operator is not certified for operating the equipment at the workcenter, the computer will not allow access to machine control programs, machine set-up information, or machine process instructions.

Once identification information has been checked and found to be correct for the equipment being operated, the machine operator is admitted to the system. At this time the machine operator will wand the bar code label on the traveler for the operation to be performed. This will immediately cause the system to display the appropriate menu screen depending on what operation and type of equipment is to be used in that operation. The menu screen will be presented to the machine operator on the standard shop floor terminal.

At the axial and DIP insertion stations, the menu screen will allow choices of: set-up optimization options (this option has been explained in depth earlier in this report as a separate cell), set-up graphics and instructions, tool path graphics for verifying the first board run, insertion program downloads, process run graphics and instructions, and specialized operations available for debugging purposes.

At the CS400-B semi-automatic assembly equipment stations, the menu screen will allow choices of: set-up graphics and instructions, component binning information, insertion program downloads, process run graphics and instructions, and specialized operations available for debugging purposes.

Conclusion

During the Factory Pilot phase of Project 32 Factoryvision, all five cells of the "To-Be" Process System were exercised, researched, and experimented with. From this hands-on testing it was determined that four of the "To-Be" Process System Cells; "Create Process Cell", "Set-up Optimization for Automatic Insertion Cell", "Storage and Control Cell", and "Machine Interface Cell" were technologically feasible and ready for implementation. The fifth cell, "Electronic Distribution Cell", is not ready for implementation at this time. With further developments and advances in application software and existing technologies, this fifth cell will be ready for implementation in the near future. Savings, as presented in the Cost Benifit Analysis section of this report, for the ten year calculation period with incorporation of the recommended four cells approach 5.5 million dollars. An additional five millon dollars of projected savings would be associated with the incorporation of the fifth cell for the same ten year time period.

"TO-BE"
MACHINE INTERFACE CELL

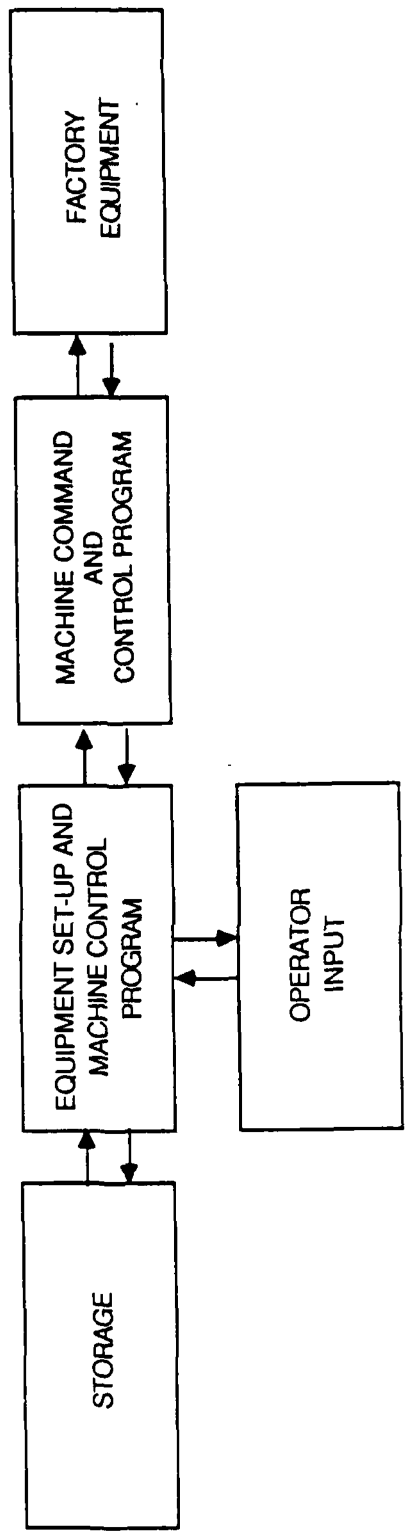


FIGURE 5.6 "TO-BE" MACHINE INTERFACE CELL

SECTION 6

PROJECT ASSUMPTIONS

Project 32 architecture and this Final Report are based on the following assumptions:

- Adequate space will be made available within the facility to install the proposed equipment.
- Labor rates used are current bid rates.
- Project 32's recommended four cells will be fully implemented in Third Quarter 1989.
- Capital equipment dollars for recommended implementation will be available Third Quarter 1988.
- Recomendation for implementation for the Electronic Distribution Cell will be forth coming in the 2nd quarter of 1989. The technology should be able to meet our requirements at that time.

SECTION 7

GROUP TECHNOLOGY CODING SYSTEM ANALYSIS

Project 32 Factoryvision uses no type of formal Group Technology Coding System. However, the "Set-up Optimization for Automatic Insertion Cell" does employ a classical feature of Group Technology in that optimized set-ups are utilized for achieving savings in set-up time and enhancing machine utilization. The decision making of optimize set-ups is being made based on the actual part numbers of the components that populate the PWA's.

SECTION 8

PRELIMINARY/FINAL DESIGN AND FINDINGS

The Project 32 Phase 2 effort consisted of a thorough evaluation, both technically and financially of a system which would provide for the creation, control, and distribution of PWB product/process information for the shop floor.

Five functional cells are required to fully implement the overall objective of Project 32:

1. Create Process Cell
2. Storage and Control Cell
3. Electronic Distribution Cell
4. Set-up Optimization for Automatic Insertion Cell
5. Machine Interface Cell

Each of the five cells will be discussed individually in this section, relating the findings found during initial CBA analysis, and how the preliminary design evolved to the final design.

1. Create Process Cell

BACKGROUND

MAvD has over 1600 Printed Wiring Assembly (PWA) part numbers in the process system. On an annual basis 60 new PWA designs are generated, and more than 1200 engineering changes to PWA's are made which result in change issues to production process information.

Due to the large annual volume of new PWA designs and engineering changes, initial CBA data revealed significant benefits in the concept of automating the portion of the Production Engineer's job, which deals with the creation and change of production process information.

The concept of automating the creation and change of PWA production process information was deemed to be feasible due to the fact that a high percentage of the PWA's have intelligent CAD data bases from which to derive the production process information. The intelligent CAD PWA data bases have been developed in the Computervision CADDS-3 and CADDS-4X environments over the last ten years.

The objective for the "Create Process Cell" was to utilize the CAD data base to extract from and build upon for the creation of production process information, and to create the production process information in an automated fashion. Central to this approach is the elimination of the need to re-transcribe and re-create both graphics and text information as presented in the "As-Is" condition.

Both an in-house and external evaluation were undertaken to determine if any of the other Honeywell facilities or any vendor had systems in place performing the functions required by Project 32's five cells.

CAPP (Computer Aided Process Planning) vendors such as General Electric with their GECAPPS system and OIR with their MULTIPLAN system were found to have technology which related to Project 32's "Create Process Cell".

The solutions offered by the CAPP vendors were eliminated for Project 32's "Create Process Cell" for the following reasons:

1. The CAPP systems were "variant process planning" systems in nature, and were based on retrieving a "similar existing process" upon which to build a "new process".

   For PWA's, the project team did not feel that a "variant process planning" system was the proper long range solution for the "Create Process Cell". The project team had determined that a "variant process planning" system would automate only 5-10 percent of a "new process" for a PWA by retrieving a "similar existing process". In terms of data input (keystrokes), 90-95 percent of a "new process" is unique to the "new" PWA because of the unique part number callouts, reference designator callouts, find-number callouts, etc.

   The project team felt that it would be feasible to "leap-frog" the "variant process planning" technology and develop a "near-generative process planning" approach which would automate 90-95 percent of the Production Engineering effort required to generate a PWA process.

2. The "variant process planning" systems did nothing to aid the Production Engineer in partitioning the hundreds of unique part number callouts into the appropriate process operations which is a significant part of the Production Engineering job.

   The project team felt that it would be feasible for a "near-generative process planning" approach to automate 90-95 percent of the Production Engineering effort required to perform the PWA parts partitioning.

3. The CAPP systems at that time did not offer an efficient technical solution for porting the CAD graphics data base into the process planning environment.

   Typically, the CAPP vendors introduced yet another graphics software system, usually severely limited in capability, into the process planning environment.

Consequently, it was determined that there was no software available in the marketplace which would meet our requirements for automated process generation. Further study revealed that the Computervision CADDS-4X data base and software provides a very good environment for the creation and change of the PWA Process Detail and CAM information by Production Engineering.

Finally, it was determined that the best solution would be internally developed software designed to operate in the CADDS-4X environment. Honeywell proceeded to develop prototype software which provides automation aids for the Production Engineer.

These automation aids will assist the Production Engineer in accomplishing the following functions:

a. The partitioning of the PWA into appropriate assembly operations (Creation of route information).

b. The creation of Operation Detail graphical instructions for PWA assembly.

c. The creation of machine programs and set-up information for the Universal Axial and DIP inserters and the Contact System semi-automatic insertion machines.

2. Storage and Control Cell

The "Storage and Control Cell" in the "As-Is" environment is simply a paperwork filing system with all the inherent problems of storage and control that go along with such a system.

In the "To-Be" environment, the "Storage and Control Cell" functionality will be accomplished electronically. The "Storage and Control Cell" functionality is an inherent part of the CADDSERVER environment.

Since the Computervision CADDSERVER/CADDSTATION hardware platforms and the CADDS-4X software environment were selected for the "Create Process Cell", no additional vendor studies were initiated for the "Storage and Control Cell".

The electronic storage functionality will be accommodated via four disk drives attached to each CADDSERVER. The four disk drives can store over 2 gigabytes of data. The process detail information, both graphics and text, and the machine NC-program data which are generated on the CADDSTATIONS in the "Create Process Cell" will be stored on the CADDSERVER's disk drives.

The control functionality will be accommodated through access control and password capabilities of the UNIX operating system software and the CADDS-4X software on the CADDSERVER. Admittance to the system will be controlled by log-in authorizations under control of a system administrator. Each data file on the system will have "read/write" access restrictions which are defined by the creator of the particular file. In other words, the Production Engineer who creates a particular piece of process information can restrict that information so that others can view the information, but not change it.

Old revisions of the process data will be archived to magnetic tape through achieving procedures under control of the system administrator. Daily backup of the process data to magnetic tape will be performed by the system administrator so that no data will be lost.

3. Electronic Distribution Cell

Due to the large volume of production process information generated in the "Create Process Cell" and the inherent problems with storage, control, and distribution in a "paper-based system", Project 32 addressed the feasibility of an "Electronic Distribution Cell" for the production process information.

The marketplace was evaluated for commercially available systems which would meet the requirements for electronic distribution of production process information in the Printed Wiring Assembly (PWA) Facility.

The Honeywell facilities in Hopkins, MN. and Seattle, WA. were both attempting to accomplish electronic distribution of process data with Apple IIE computers. With a major concern being an interface to the MAvD CAD system as a source for deriving the CAM and process graphic information, these systems were eliminated from our consideration for the following reasons:

a. The graphics had to be manually input into these systems. There was no facility to transport CAD data bases into the Apple environment.

Since the number of PWA's in MAvD's process system was greater by an order of magnitude than the other Divisions were dealing with, it was apparent that the job of manually inputting the graphics would be excessive.

b. The resolution of the graphics on the Apple shop floor terminals was not deemed to be sufficient for display of MAvD's more densely populated PWA's.

Next, the project team began to look externally to determine if there were any vendors which had existing technology that could be used to accomplish the functionality required by Project 32's "Electronic Distribution Cell".

Expositions were attended such as AUTOFACT where there were over 300 vendors displaying their technology. At that time, the findings were as follows:

Computervision, Inc. was found to have technology which related to three of Project 32's five cells:

- Storage and Control Cell
- Electronic Distribution Cell
- Machine Interface Cell

Next, the project team negotiated with Computervision to provide Factoryvision hardware and software for evaluation. The system was first evaluated in an engineering environment, and then moved into a factory pilot environment.

As a result of the factory pilot, the system requirements for the "Electronic Distribution Cell" were re-evaluated and re-determined, especially in the areas of system response and performance, operator interface, and graphics displays.

Enhancement requests were presented to Computervision. However, due to the complexity of the changes required to meet our requirements, Computervision was unable to implement the changes within the time frame scheduled for the factory pilot.

Consequently, implementation of the "Electronic Distribution Cell" at this time is not recommended, but rather, that the "Electronic Distribution Cell" technology be submitted for further study and development. All the technologies required presently exist, but the appropriate display technology must be selected and software must be developed to accommodate the technology selected.

During the course of our study on Project 32, the technologies upon which implementation of the project are based have been advancing at a tremendous rate. For example, the original fileserver/cpu which Computervision consigned to us had a 68010 processor running about 1-MIPS (millions of instructions per second) with 3 megabytes of RAM system memory. Three generations of processors have since evolved. By the end of 1988, a fileserver (CADDSERVER) will be available with a 68020 processor running at 10 MIPS with 32 megabytes of RAM memory.

The problem is that the Factoryvision software, which we were relying on for accomplishing the "Electronic Distribution Cell", has not evolved at the same rate.

Presently, the project team is working with Computervision, as our first choice, to determine if an "Electronic Distribution System" can be developed to meet our requirements for the Printed Wiring

Assembly Facility. If Computervision cannot meet our requirements, we will have to investigate other vendors or consider in-house development.

The key areas of concern are:

1. The display times for graphics to the production operators, including the capability to randomly "page around" within a graphics sequence.

2. Display device (graphics terminal) dependency on the Factoryvision software.

3. Flexibility to tailor menus and operator interface.

1. Display Time For Graphics

Our requirement for display time is that the first graphics display will take no more than 10 seconds, and that sequential displays will take no more than 2 seconds. In addition, the operator must be able to "page forward and backward" within a sequence of graphics displays.

In order to meet this requirement, the Factoryvision software will have to be modified, the link between the host CADDSERVER and the graphics display device will have to run faster, the display file format will have to be changed and the graphics display device will have to be changed.

2. Display Device (Graphics Terminal)

Presently, certain parts of the Factoryvision software result in a display device dependency. That dependency is on the Modgraph GX-1105 terminal and Tektronics 4010 graphics format. In addition, the Modgraph is limited to a host-terminal RS-232 communication link running at a maximum speed of 19,200 baud.

In order to meet our requirements for speed and flexibility, we would like to see Computervision modify the Factoryvision software so that it would be device independent, and then provide device drivers for alternate output graphics displays.

Secondly, the price of low-end engineering workstations has decreased so rapidly that the concept of using a workstation class of device on the shop floor is a reality. This approach would open the door to utilizing Ethernet communication links between host and shop floor terminal, resulting in faster communications (10 MB as opposed to 19.2 KB) and additional terminal capabilities.

3. Flexibility To Tailor Menus and Operator Interface

Although the Factory application software presently allows some degree of user definable feature for menus, etc., we would like to see modifications made to provide even more tailoring to simplify production operator interfaces.

Without integration, the "Electronic Distribution Cell" would require an additional barcode wand and some redundant wanding transactions.

SECTION 9

SYSTEM/EQUIPMENT/MACHINING SPECIFICATIONS

The purpose and intent of the specifications is to outline and define Honeywell's (Military Avionics Division) requirements for the "Electronic Distribution Cell" in the Printed Wiring Assembly Factory environment.

System Requirements

1. The operator interface must be very simple and straight forward.

   a. Stepping through "menus" should be kept to a minimum. Forward and backward stepping capability is required.

   b. The system should be adaptable to using operator interfaces, such as a foot switch for advancing forward and backward through graphics sequences. A custom keypad and barcode readers are other interfaces under consideration.

   Reason: In an assembly line environment such as MAvD's Printed Wiring Assembly Factory, operators "page" through approximately 2,000,000 pages of instructions per year. Even the smallest increment of time, whether it is attributable to the operator waiting for a graphics display or looking for a key on a keyboard has a significant impact on the overall direct labor. For example, a 10 second delay per page in waiting for graphics extended across the 2,000,000 "pages" per year is the equivalent of two (2) man-years of waiting.

   Reason: By putting a computer keyboard in front of an operator, MAvD is facing union issues which could require that the assembly operator be given a labor grade rating equivalent to a computer operator, a bump of 1-2 labor grades. The cost impact is obvious. This is one of reasons why we are considering alternative input devices.

2. The system must be capable of supporting 80 shop floor terminals and 12 assembly machines simultaneously. The assembly machine interface will be an RS-232 interface.

3. The system must be capable of handling multiple issues of process instructions (both text and graphics) simultaneously.

   Reason: It is possible that two different job orders for different revisions of the same part-number can be in-process at the same time.

4. The system must be capable of storing approximately 36,000 graphics display files for PWA (Printed Wiring Assembly) instructions (1500 part numbers @ 24 pages each) and 4,500 ASCII programs for PWA assembly machines.

5. Menus options at all levels must be able to be customized based on "access group", and in certain cases, workcenters. "Access groups", for example, would be assembly operators, machine operators, set-up personnel, inspectors, Production Engineers, etc.

   Reason: In order to simplify the operator interface, the project team does not want the operator pondering over menu selections which he/she should not be concerned with.

6. "Sub-menus" such as instructions for use of function keys for zoom, scroll, paging, etc. or "pop-up menus" must be completely tailorable based on "access group", and in certain cases, workcenters. The location of these menus must be easily configured by user so as not to interfere with graphics display areas.

   Reason: At certain workcenters and for certain "access-groups", the project team does not want to present the option to do certain functions, such as zoom, scroll etc. If a "zoom", for example, is required at a certain point in the process, the Production Engineer responsible for the process will set up an appropriate display file.

7. It must be feasible for the user to configure additional menus for certain "access-groups" or workcenters.

   Reason: During certain processes, it may be necessary to have a screen which instructs the operator to input Assembly Configuration Information (ACI data) or inspection information, and for the system to store that information on an assembly serial number basis.

8. The system must be extremely reliable, and the supplier must provide a recommended approach to enable the user to get back on-line in the event of major system component failure, i.e. cpu, disk drive, etc.

9. The system must be capable of providing for a sequence of graphics to be paged through, either forward, or backward, with a single key stroke or by foot pedal, or randomly with a minimum of keystrokes.

   a. Maximum number of sequential frames is 75.

   b. Maximum display time for the first frame in a sequence of graphics frames is ten seconds.

   c. Maximum display time for succeeding frames is two seconds.

   d. Maximum time for random access of a graphics frame is ten seconds.

   Reason: Reference requirement #1 - the large number of "pages" that are accessed annually in this factory.

   Solution consideration: A data base table will be used to define a stack of display files for a given process sequence. It would be desirable that a utility be included to establish the default sequence table based on a sort of the directory/file names of display files. The data base table would still need to be capable of being configured in order for the engineer to add other display files which he may want to include in the sequence.

10. It must be possible to interrupt a sequence of graphics/text displays in order to reference a secondary sequence of display files via a return to previous menu item or help key. Upon completing reference to the secondary sequence, the system must be capable of returning to the point of departure in the original sequence.

Reason: It is sometimes necessary to refer to reference documents such as SOD's (Standard Operating Details) in-stream.

Display Device Requirements

1. A color display capable of displaying a minimum of 16 colors is mandatory.

2. The display device must have a resolution on the order of approximately 1000 X 800 pixels.

   Reason: Nearly all of our process instructions for PWA's include a great amount of detail. Detail such as reference designator text is extremely small and must be readable by the operator.

3. The display device would ideally be a 13-15 inch device, but the footprint of the device should not exceed 180 square inches.

   Reason: Assembly line workstations are usually quite compact and crowded.

4. The display device must meet ESD (Electro-Static Discharge) requirements for an electronics assembly environment.

5. The display device must provide an adequate display in a factory environment which has ambient non-glare lighting.

Other Requirements

1. The project team would like to encourage the proper vendor solution to the system/display device interface problem.

   The project team feels that the system software should be device independent of the display device technology chosen. Future implementation of shop floor graphics systems in other factories may have differing requirements. Enhanced Graphics Adapter (EGA) quality of graphics may be acceptable in some factories, while a 19 inch high resolution display may be required in another factory.

   The project team would like to encourage exploration into the use of low-end engineering workstations or networked PC's as possible alternative display devices.

2. Graphics display file format should be efficient and compact in order to meet display response requirements and system storage requirements.

3. Assuming that display files are to be created in the CADDS environment, the time for the Production Engineer to generate such display files should typically be on the order of 1-2 minutes or less. We would rather spend the time creating an efficient display file in this environment rather than repeatidly suffer the consequences of operating with inefficient display file technology in the factory.

The typical graphics displays for this factory will be PWA's with 200-300 components and reference designator text and 1000-1500 component pads. Minimal textual instructions will be on the graphics frames.

Since the circular pads are significant drivers of display file size, the CADDS software which creates the display files should contain options for "courseness/fineness".

SECTION 10

TOOLING SPECIFICATION

Project 32 Factoryvision uses no tooling.

SECTION 11

VENDOR/INDUSTRY ANALYSIS/FINDINGS

Background

Project 32 Phase 2 effort involved the investigation of technologies, hardware, software, systems integration, and human factors required to meet the objectives of this project.

Initial evaluation of our requirements, initial design for the project, and initial evaluation of vendor equipment and software were targeted toward achieving functionality which met the requirements for the following five project cells:

1. Create Process Cell
2. Storage and Control Cell
3. Electronic Distribution Cell
4. Optimization for Automatic Insertion Cell
5. Machine Interface Cell

Vendor/Industry Analysis/Findings

The first phase of MAvD's vendor/industry analysis began with an in-house evaluation to determine if any of the other Honeywell facilities had systems in place performing the functions required by the five Project 32 cells.

Of the five cells, we found related technology implemented in-house in only the "Electronic Distribution Cell".

The Honeywell facilities in Hopkins, MN and Seattle, WA were both attempting to accomplish electronic distribution of process data with Apple IIE computers. With a major concern being an interface to the MAvD CAD system as a source for deriving the CAM and process graphics information, these systems were eliminated from our consideration for the following reasons:

1. The graphics had to be manually input into these systems. There was not a facility to transport CAD data bases into the Apple environment.

   Since the number of PWA's in MAvD's process system was greater by an order of magnitude than the other Division's we were dealing with, its was apparent that the job of manually inputting the graphics would be excessive.

2. The resolution of the graphics on the Apple shop floor terminals was not deemed to be sufficient for display of MAvD's more densely populated PWA's.

Next, we began to look externally to determine if there were any vendors which had existing technology that could be used to accomplish the functionality required by the five Project 32 cells.

Expositions were attended, such as AUTOFACT, where there were over 300 vendors displaying their technology. At that time, the findings were as follows:

1. Computervision, Inc. was found to have technology which related to three of Project 32's five cells:

   - Storage and Control Cell
   - Electronic Distribution Cell
   - Machine Interface Cell

2. CAPP (Computer Aided Process Planning) vendors such as General Electric with their GECAPPS system and OIR with their MULTIPLAN system were found to have technology which related to Project 32's "Create Process Cell".

   These CAPP vendors were also planning logical future extensions of their systems to include electronic distribution to shop floor terminals, but offered no product at that time.

The solutions offered by the CAPP vendors were eliminated for Project 32's "Create Process Cell" for the following reasons:

1. The CAPP systems were "variant process planning" systems in nature, and were based on retrieving a "similar existing process" upon which to build a "new process".

   For PWA's, we did not feel that a "variant process planning" system was the proper long range solution for the "Create Process Cell". We had determined that a "variant process planning" system would automate only 5-10 percent of a "new process" for a PWA by retrieving a "similar existing process". In terms of data input (keystrokes), 90-95 percent of a "new process" is unique to the "new" PWA because of the unique part number callouts, reference designator callouts, find-number callouts, etc.

   We felt that it would be feasible to "leap-frog" the "variant process planning" technology and develop a "near-generative process planning" approach which would automate 90-95 percent of the Production Engineering effort required to generate a PWA process.

2. The "variant process planning" systems did nothing to aid the Production Engineer in partitioning the hundreds of unique part number callouts into the appropriate process operations which is a significant part of the Production Engineering job.

   We felt that it would be feasible for a "near-generative process planning" approach to automate 90-95 percent of the Production Engineering effort required to perform the PWA parts partitioning.

3. The CAPP systems at that time did not offer an efficient technical solution for porting the CAD graphics data base into the process planning environment.

   Typically, the CAPP vendors introduced yet another graphics software system, usually severely limited in capability, into the process planning environment.

As a result of the above findings, and for the reasons following, we decided to take the approach of internally developing the "Create Process Cell".

The objective for the "Create Process Cell" was to utilize the CAD data base to extract from and build upon for the creation of production process information, and to create the production process information in an automated fashion. Central to this approach is the elimination of the need to re-transcribe and re-create both graphics and text information as presented in the "As-Is" condition.

It was determined that there was no software available in the marketplace which would meet our requirements for automated process generation.

The concept of automating the creation and change of PWA production process information was determined to be feasible due to the fact that a high percentage of these PWA's have intelligent CAD data bases from which to derive the production process information. The intelligent CAD PWA data bases have been developed in the Computervision CADDS-3 and CADDS-4X environments over the last ten years.

Studies revealed that the Computervision CADDS-4X data base and software provides a very good environment for the creation and change of the PWA Process Detail and CAM information by Production Engineering.

Finally, it was determined that the best solution would be internally developed software designed to operate in the CADDS-4X environment. Honeywell proceeded to develop prototype software which provides automation aids for the Production Engineer as follows:

1. The partitioning of the PWA into appropriate assembly operations. (Creation of route information).

2. The creation of Operation Detail graphical instructions for PWA assembly through utilization of the CAD graphics data base.

3. The creation of machine programs and set-up information for the Universal Axial and DIP inserters and the Contact Systems semi-automatic insertion machines.

A significant advantage to this approach is that the CAD data base and the "Create Process Cell" utilize the same CADDS-4X data base, and that all five Project 32 cells can be hosted on the same hardware platform.

SECTION 12

EQUIPMENT/MACHINERY ALTERNATIVES

The Computervision Factoryvision system was chosen for Project 32 because its architecture and application software was compatible with the Computervision CAD system data bases used at Honeywell. This, coupled with the fact that Project 32 is pushing the leading edge of the technology available today, and the initial assumption that Factoryvision was the only system that was capable of fulfilling Project 32's requirements at the start of Phase 2, was why Computervision Factoryvision was chosen. There were and are no alternates that fulfilled the requirements of Project 32. Computervision is located in Bedford, Massachusetts.

SECTION 13

MIS REQUIREMENTS/IMPROVEMENTS

For the Phase 2 study and Factory Pilot, the only system interface required was with the CAD data base system. This interface was physically made through the Engineering ETHERNET system. The information transferred by the CAD system to the Project 32 Factoryvision System were Printed Wiring Assembly parts lists and CAD drafting data bases on the assemblies that have production processes written for them. Because of the compatibility between the Computervision CAD system and the Computervision Factoryvision System used, the system interface functioned well during the Phase 2 study and the Factory Pilot. These interfaces require no further development at this time.

SECTION 14

COST BENEFIT ANALYSIS/PROCEDURES

The analysis of Project 32 is based upon installation of Factoryvision within the printed wiring board area at Honeywell's Military Avionics Division in St. Louis Park. The cost savings were calculated based on the implementation of the following four cells: 1) Create Process Cell, 2) Storage and Control Cell, 3) Machine Interface Cell, and 4) Set-up Optimization for Automatic Insertion Cell. The fifth cell, Electronic Distribution Cell, has not been used in the CBA calculations because this portion is not technically feasible at this time.

Below are the three Factoryvision cost drivers used to calculate the savings and methodology used to evaluate them. The methodology diagram for the identified cost drivers is shown in Figure 14.1.

1. "As-Is" AI Set-up: The number of jobs processed on automatic insertion equipment equates with number of automatic insertion equipment set-ups. The average lot size per job equals 48.

   "To-Be" AI Set-up: Job families will be formed which will enable family set ups on the automatic insertion equipment. Job families will range from three to six jobs per family. In the cost savings calculations, a conservative three jobs per family was used.

2. "As-Is" Production Engineering Time: The production engineer determines the layout process, compares the parts list with the printed wiring board, partitions the parts into operations, determines the necessary fixtures and tooling, and determines the time standard.

   "To-Be" Production Engineering Time: Through the highly interactive tutorial software, the production engineer will only be required to define the operations and machine to be used in the process. All actual creation of the processes will be done automatically by system software.

3. "As-Is" Senior Production Engineering Aide: The senior production engineering aide is responsible for creating and processing the machine programs and process graphics details.

   "To-Be" Senior Production Engineering Aide: The Factoryvision system software will automatically create machine programs and supplementary graphics as defined by the production engineer.

CAPITAL AND EXPENSE

The capital, recurring and non-recurring expenses for Project 32 are shown on Figure 14.2.

PROJECT SAVINGS AND CASH FLOWS

The savings to be realized on this project exceed Honeywell's Military Avionics Division hurdle rate. The project's cash flow information is shown on Figure 14.3 with the assumption that capital will be available per the implementation plan.

PROJECT 32 CBA METHODOLOGY

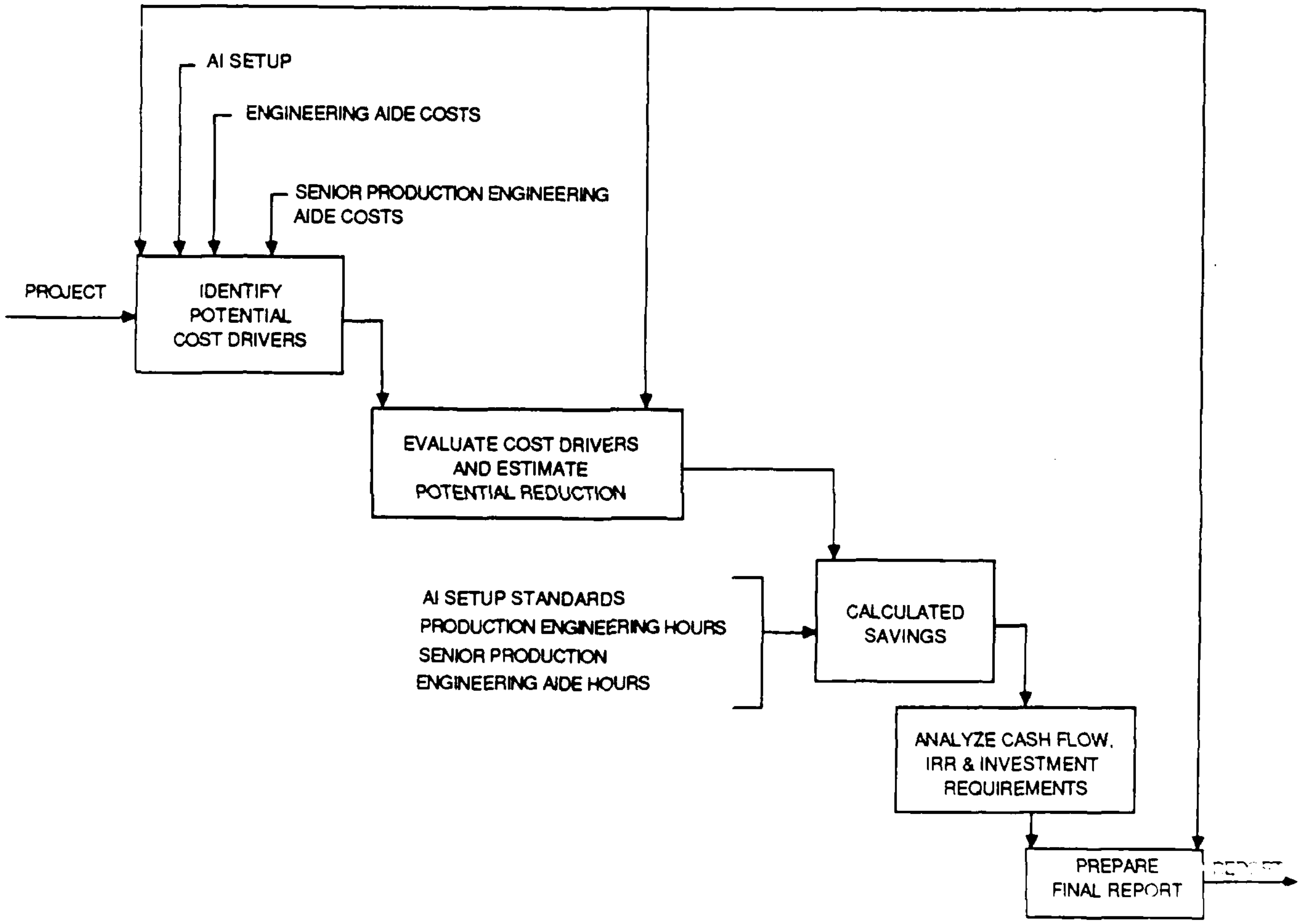


FIGURE 14.1 COST BENEFIT ANALYSIS METHODOLOGY

CREATION OF PROCESS CELL

PROJECT 32 -- EXPENDITURE SCHEDULE

PHASE 3

CAPITAL COSTS	COST	CAPITALIZATION DATE
Computer Equipment		
32 CV Workstation	$28,975	1988
32 CV Workstation	$28,975	1988
32 CV Workstation	$28,975	1988
Memory Exp 4 Meg	$4,636	1988
Memory Exp 4 Meg	$4,636	1988
Memory Exp 4 Meg	$4,636	1988
Ethernet Interface Card	$1,159	1988
Ethernet Interface Card	$1,159	1988
Ethernet Interface Card	$1,159	1988
Software	$28,000	1988

Total Computer Equipment	$133,990	1988
Furniture Costs		
Desk and Cabinets	$8,693	1988
TOTAL CAPITAL COSTS	$142,683	1988
EXPENSE COSTS		YEAR EXPENSED
Non-Recurring Expenses		
Area Preparation	$4,500	1988
Training	$8,500	1988
Software Implementation	$57,090	1988

TOTAL NON-RECURRING EXPENSES	$70,090	1988
TOTAL CAPITAL + NON-RECURRING	$212,773	

RECURRING EXPENSES

* **Annual Hardware Maintenance**	$10,265

* begins in 1989

FIGURE 14.2 CREATE PROCESS CELL

STORAGE AND CONTROL CELL

PROJECT 32 -- EXPENDITURE SCHEDULE

PHASE 3

CAPITAL COSTS	COST	CAPITALIZATION DATE
Computer Equipment		
Decwriter II Line Printer	$1,159	1988
34C FIle Server	$28,975	1988
Memory Exp 8 Meg	$9,272	1988
Ethernet Interface	$1,259	1988
Graphics Accel	$5,795	1988
Disk Pack #1	$24,339	1988
Disk Pace #2	$11,590	1988
Disk Pack #3	$19,703	1988
Disk Pack #4	$11,590	1988
Plotter Control Card	$3,477	1988
1/2" Magnetic Tape Drive	$11,590	1988
19" Color Terminal	$17,385	1988
Versatec #C2558 Color Plotter	$31,293	1988
Software	$28,000	1988

Total Computer Equipment	$205,427	1988
Furniture Cost		
Desk and Cabinets	$2,898	1988
TOTAL CAPITAL COSTS	$208,325	1988

EXPENSE COSTS		YEAR EXPENSED
Non-Recurring Expenses		
Area Preparation	$1,500	1988
Training	$2,500	1988

TOTAL NON-RECURRING EXPENSES	$4,000	1988
TOTAL CAPITAL + NON-RECURRING	$212,325	
RECURRING EXPENSES		
* **Annual Hardware Maintenance**	$11,356	

* begins in 1989

FIGURE 14.2 (continued) STORAGE AND CONTROL CELL

INTERFACE WITH ASSEMBLY MACHINE CELL

PROJECT 32 -- EXPENDITURE SCHEDULE

PHASE 3

	COST	CAPITALIZATION DATE
CAPITAL COSTS		
Computer Equipment		
Modgraph GX 1105	$5,795	1988
Modgraph GX 1105	$5,795	1988
FX-80 Printer	$1,159	1988
FX-80 Printer	$1,159	1988
Interface Cable	$1,739	1988
Interface Cable	$1,739	1988

TOTAL CAPITAL COSTS	$17,386	1988

		YEAR EXPENSED
EXPENSE COSTS		
Non-Recurring Expenses		
Run Cables	$500	1988

TOTAL CAPITAL + NON-RECURRING	$17,886

FIGURE 14.2 (continued) MACHINE INTERFACE CELL

SUMMARY OF THREE CELLS

PROJECT 32 -- EXPENDITURE SCHEDULE

PHASE 3

	COST	CAPITALIZATION DATE
TOTAL CAPITAL		
COMPUTERS	$356,803	1988
FURNITURES	$11,591	1988

TOTAL CAPITAL COSTS	$368,394	1988
		YEAR EXPENSED
EXPENSES		
Non-Recurring	$74,590	1988
TOTAL CAPITAL + NON-RECURRING	$442,884	
* TOTAL RECURRING	$21,621	
* begins in 1989		

FIGURE 14.2 (continued) SUMMARY OF THREE CELLS

12/29/87

TECH MOD PHASE 2

PROJECT 32

PROJECT CASH FLOW SUMMARY

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	TOTAL
Capital	$368,394	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$368,394
Non-Recurring Expenses	$74,590	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$74,590
Recurring Expenses	$0	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$21,621	$237,831
Total Savings	$0	$132,592	$353,178	$455,673	$483,509	$518,052	$552,242	$590,333	$631,052	$671,004	$715,132	$366,665	$5,467,432
Depreciation	$36,163	$72,326	$72,326	$72,326	$72,326	$36,646	$966	$966	$966	$966	966	$1,451	$368,394

FIGURE 14.3 PROJECT CASH FLOW SUMMARY

SECTION 15

IMPLEMENTATION PLAN

At this point in time, Fourth Quarter 1987, the Computervision Factoryvision software program does not fulfill the production requirements for complete implementation. Because of this fact, we do not recommend full implementation of Project 32 at this time. However, four of the five cells within Project 32 do fulfill production requirements. With this in mind, we recommend implementing the Create Process Cell, Set-up Optimization for Automatic Insertion Cell, Machine Interface Cell, and the Storage and Control Cell will be implemented starting the third quarter of 1988. (Figure 15.1).

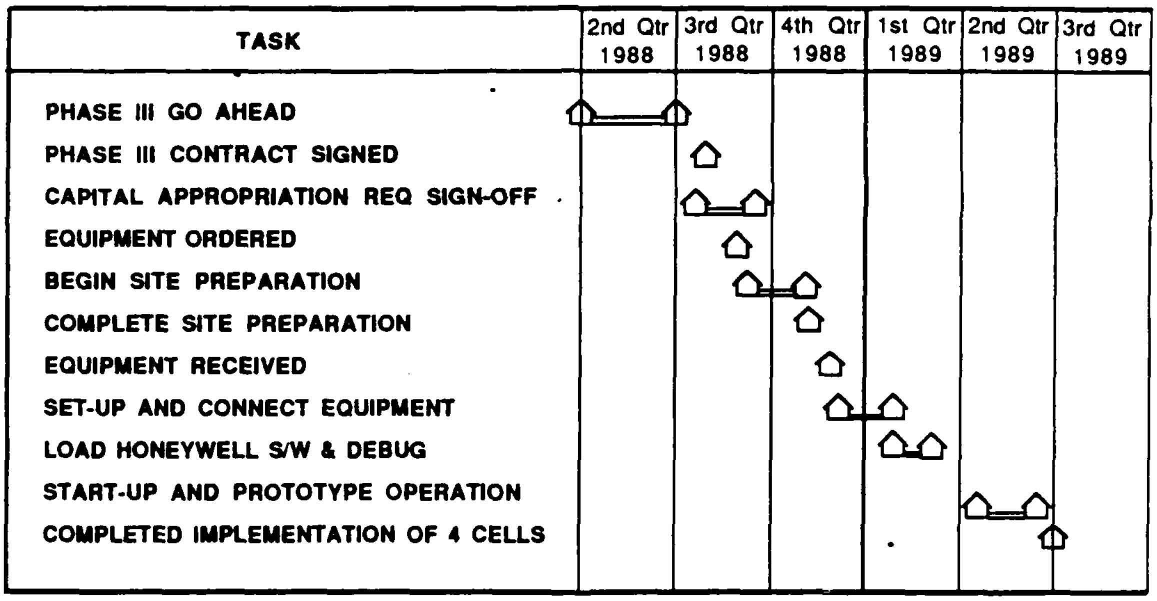


FIGURE 15.1 PROJECT 32 IMPLEMENTATION SCHEDULE

SECTION 16

PROBLEMS ENCOUNTERED and HOW RESOLVED

Create Process Cell

Problem: MAvD's migration from the Computervision CADDS-3 environment to the CADDS-4X data base environment for PWA's created a data base compatibility problems.

Solution: Advanced Manufacturing Technology (AMT) engineers generated and installed a procedure for converting the CADDS-3 PWA data bases to CADDS-4X data bases. Computervision software existed to make the conversion, but a significant effort was required to convert component library figures and document the conversion procedure.

Problem: Migration from the old Computervision CGP-200X hardware platform to the new UNIX CADDSTATION environment. This migration is very desirable in terms of achieving a long term stable state-of-the-art hardware platform, but nevertheless not without problems. Programming languages such as TPL and Fortran-S which were resident on the CGP-200X were abandoned in the changeover to the UNIX environment in favor of "C", Pascal and Fortran-77. Also, certain CADDS commands were not ported by Computervision to the UNIX environment.

Solution: In writing the prototype software for the "Create Process Cell", special care had to be taken to assure that the software would easily port to the UNIX environment. Some of the software will still have to be rewritten to run in the UNIX environment during early 1988.

It was only recently that Computervision agreed to port certain commands required by the "Create Process Cell" to the UNIX environment. This porting will be done by first quarter 1988, so that our schedule to migrate the "Create Process Cell" to the CADDSTATION will not be impacted.

Electronic Distribution Cell

Problem: The initial consignment of hardware provided by Computervision was a 68010 based CPU. Our initial evaluation of the Factoryvision software on this platform seemed to indicate that the system response was to slow.

Solution: Computervision consigned a new 68020 based CADDSERVER in January, 1987. Response improved significantly.

Since receipt of the new CADDSERVER, two new generations of CADDSERVERS have been released, with speed enhancements of over five-fold.

Problem: Color graphics display was not initially available.

Solution: Computervision implemented color display functionality, and the Modgraph GX-1000 terminals were replaced with Modgraph GX-1105 terminals.

Problem: Due to the large size of the display files for the PWA data bases, graphics display times was deemed unacceptable.

Production operator interface was seen to be too complicated, and "paging" through a sequence of graphics displays was too cumbersome and slow.

Solution: Speed enhancements from 9600 baud to 19,200 baud were found to be limitations due to features of the Ingress data base.

Computervision is converting the Factoryvision application to the Oracle data base.

Computervision was unable to implement a more automated approach to "paging" through a graphics sequence. This is a key item which can be addressed with further development.

Operator interface remains cumbersome. This item can be addressed with further development.

Problem: The Modgraph GX-1105 terminal is too large and bulky for incorporation into an ergonomic operator workstation environment.

Solution: Although the Modgraph GX-1105 terminal provides very good quality graphics display, we would like to see changes made to the Factoryvision application software which would provide for display device independence, thus enabling a wider selection of graphics terminals for shop floor display. This item can be addressed with further development.

SECTION 17

AREAS FOR FUTURE CONCERNS/DEVELOPMENT

Although the four cells recommended for Phase 3 implementation (the Create Process Cell, the Storage and Control Cell, the Set-up Optimization for Automatic Insertion Cell and the Machine Interface Cell) will be nicely integrated, the following four areas of concern will eventually need to be addressed in order to achieve the desired level of total integration within the Printed Wiring Assembly Factory:

1. Implementation of the fifth cell originally proposed by this project, the "Electronic Distribution Cell".

2. Integration with the Computerized Storage Retrieval System (CS/RS) computer system.

3. Integration with the MAvD business operating system (HMS/BOS).

4. Accommodation of new Manufacturing Technologies into the "Create Process Cell" as they emerge into the Printed Wiring Assembly Factory, i.e. surface mount technology.

Implementation of the Electronic Distribution Cell

The Project 32 Team feels that implementation of this cell can be accomplished with an expanded scope of Phase 2 study effort. All the technologies required presently exist, but the appropriate display technology must be selected and software must be developed to accommodate the selected display technology.

During the course of our study on Project 32, the technologies upon which implementation of the project are based have been advancing at a tremendous rate. For example, the original fileserver/cpu which Computervision consigned to us had a 68010 processor running about 1 MIPS (millions of instructions per second) with 3 megabytes of RAM system memory. Three generations of processors have since evolved. By the end of 1988, a fileserver (CADDSERVER) will be available with a 68020 processor running at 10 MIPS with 32 megabytes of RAM memory.

The problem is that the Factoryvision software, which we were relying on for accomplishing the "Electronic Distribution Cell", has not evolved at the same rate.

Presently, we are working with Computervision, as our first choice, to determine if an Electronic Distribution System can be developed to meet our requirements for the Printed Wiring Assembly Factory. If Computervision cannot meet our requirements, we will have to investigate other vendors or consider in-house development.

The key areas of concern are:

1. The display times for graphics to the production operators, including the capability to randomly "page round" without a graphics sequence.

2. Display device (graphics terminal) dependency on the Factoryvision software.

3. Flexibility to tailor menus and operator interface.

Display Time For Graphics

Our requirement for display time is that the first graphics display will take no more than 10 seconds and that sequential display will take no more than 2 seconds. In addition, the operator must be able to "page forward and backward" within a sequence of graphics displays.

In order to meet this requirement, the Factoryvision software will have to be modified, the link between the host CADDSERVER and the graphics display device will have to run faster, the display file format will have to be changed and the graphics display device will have to be changed.

Display Device

Presently, certain parts of the Factoryvision software result in a display device dependency. That dependency is on the Modgraph GX-1105 terminal and Tektronics 4010 graphics format. In addition, the Modgraph is limited to a host-terminal RS-232 communication link running at a maximum speed of 19,200 baud.

Secondly, the price of low-end engineering workstations has decreased so rapidly that the concept of using a workstation class of device on the shop floor is a reality. This approach would open the door to utilizing Ethernet communication links between host and shop floor terminal, resulting in faster communications (10 MB as opposed to 19.2 KB) and additional terminal capabilities.

Flexibility to Tailor Menus and Operator Interface

Although the Factoryvision application software presently allows some degree of user defined feature for menus, etc., we would like to see modifications made to provide even more tailoring to simplify production operator interfaces.

Integration with The CS/RS System

Presently, the Production Operator must perform barcode wanding transactions to the CS/RS system. These wanding transactions log-in the operator, initiate the delivery of work to the operator, report job completion, etc.

Without integration, the "Electronic Distribution Cell" would require an additional barcode wand and some redundant wanding transactions.

Integration With The MAvD Business Operating System (HMS/BOS)

There is a definite long term need to integrate the "Create Process Cell" with the business operating system. The prototype software for the "Create Process Cell" eliminates the re-transcription of the design data by the Production Engineer into the "Create Process Cell". However, it is still necessary to input all the parts callouts etc. via the PMS (Process Management System) summary into the business operating system. Collectively for the PWA processes, this amounts to millions of keystrokes inputs on an annual basis, with all the inherent opportunities for error.

Integration of the "Create Process Cell" with the business operating system will provide for an electronic flow of this data, thereby eliminating the manual inputting of data.

Incorporation of New Manufacturing Technologies

As new products and new manufacturing technologies are introduced into the Printed Wiring Assembly Factory, provisions for accommodating such changes will have to be incorporated into several systems.

For example, the incorporation of Surface Mount Technology (SMT) components will require changes to our CADD system design process procedures and component libraries. The manufacturing rules and assembly criteria will have to be incorporated into the "Create Process Cell". Provisions to accommodate new SMT pick-and-place equipment will have to be incorporated into the "Machine Interface Cell".

However, both the "Create Process Cell" and the "Machine Interface Cell" were designed to be modular in order to be able to readily accept such changes without impacting any of the other software modules.